POWER PLANT ENGINEERING

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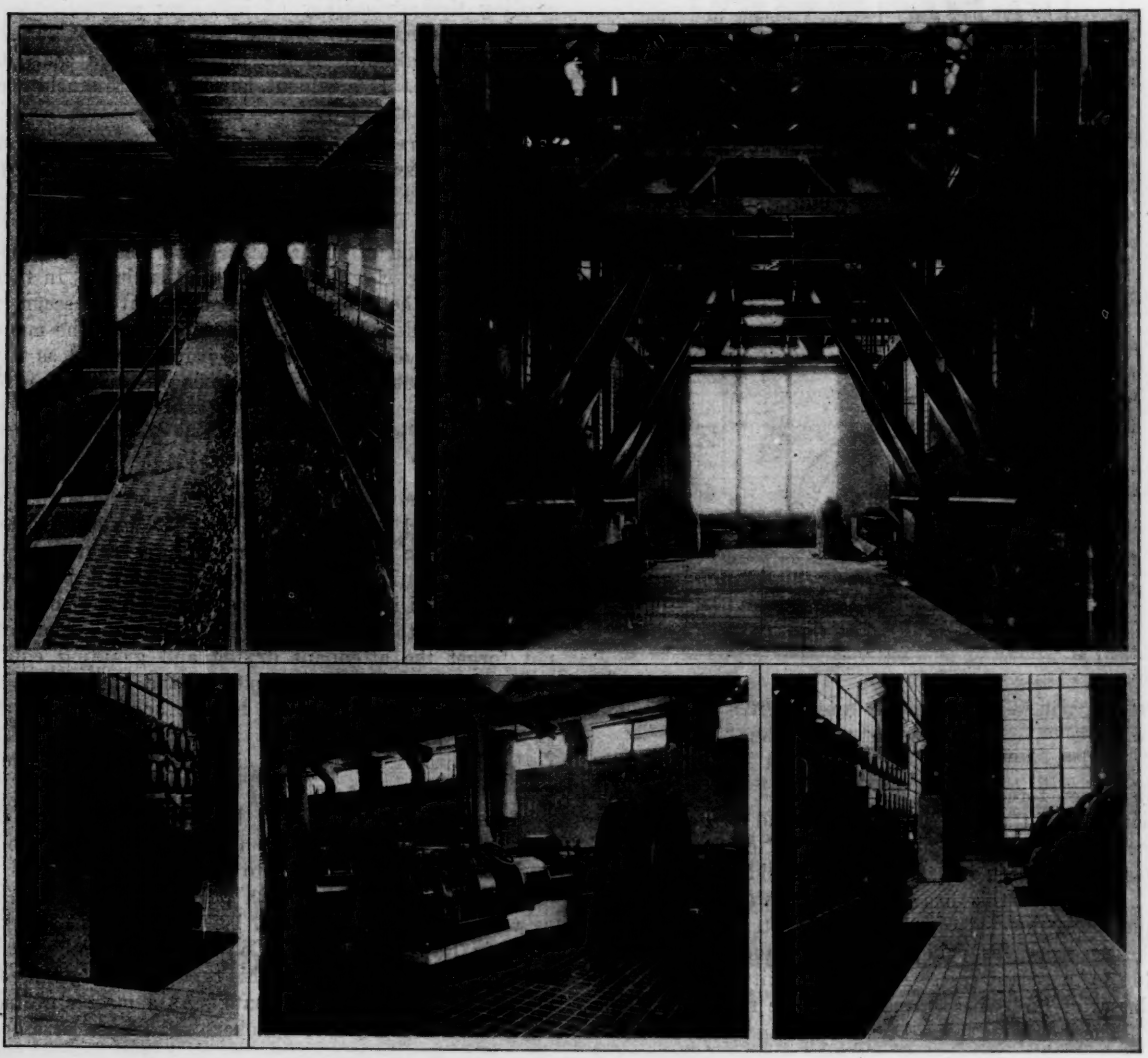
Power Plant Operation Number

OPERATION is the most vital factor in getting plant economy. Advantages of the latest and most expensive equipment, the most careful planning, co-ordination and installation of a plant may all be nullified by careless or ignorant operation.

We have all seen plants with crude machinery operated so as to give remarkably good results; also plants with good equipment so managed that the results were a great disappointment.

Adequate records carefully studied, intelligent, systematic routine for operation and inspection, with provision for immediate correcting of wasteful conditions, are the essentials of good operation.

Orderly progress in improvement of economy is secured by making certain that present equipment is being operated in the best way; then by replacing inefficient machinery with that which can be shown to pay a profit on its cost, until the whole plant is showing a maximum return per dollar of total expense, including operating cost and overhead.



Resume of the Boiler Situation

INCREASE IN COST OF FUEL HAS STIMULATED MARKED DEVELOPMENT IN BOILERS, FURNACES AND OTHER EQUIPMENT; IMPROVEMENT IN STATUS OF BOILER ROOM PERSONNEL. BY A. D. BAILEY

IT IS evident that the marked increase in fuel costs during the past few years has been a great stimulus to stoker and boiler development, and has had a more beneficial effect upon the design, construction and operation of this equipment than any amount of conservation agitation has been able to accomplish over a much longer period. Added to this has been the marked increase in the cost of boiler and stoker equipment, so that users have been forced to get the utmost out of new installations and in many cases have found it necessary to increase the capacity and efficiency of equipment which has already been in service for a considerable time.

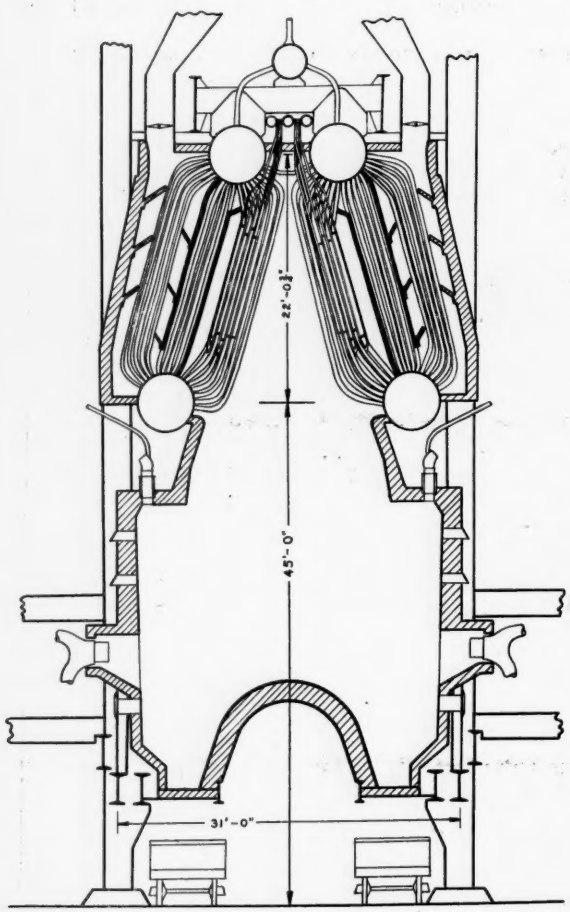


FIG. 1. BOILER ARRANGED TO BURN BOTH POWDERED FUEL AND BLAST FURNACE GAS

Added to this has been the constantly decreasing quality of the coal supplied for industrial purposes and the necessity for using fuels of a much poorer grade due to increased cost. Also the substitution of inferior classes of fuel where these were more readily available.

The net result has been in the increase in size of the boilers themselves and of the fuel-burning equipment supplied with them, along with an increase in the amount of fuel burned per unit of area on the stokers, as well as an increase in the amount of evaporation per square foot of heating surface in the boiler.

Increased boiler capacity and increased fuel cost have resulted in the use of integral economizers becoming almost standard practice in large installations particularly, although in some instances there has been a reaction towards a higher boiler with increased flue gas travel in the boiler itself, so that the economizer and its attendant expense both for investment and operating is in part at least, eliminated. In these installations it is customary, by bleeding the main turbine, to heat the feed water to a temperature suitable for direct feed to the boiler, the reduction in flue gas temperature being obtained by the longer gas travel in the boiler itself and the additional heating surface interposed.

While each case should be considered individually regarding the advisability of installing economizers, it has been estimated by some engineers that for eastern coals such equipment is not justified with a coal cost below $8 a ton. It is evident, however, that no arbitrary figure can be stated covering all conditions.

There has recently been no marked increase in steam pressure and temperatures, 350 lb. remaining about the limit for boiler installations in this country and abroad, although one English installation has reached 450 lb.

The question of superheat remains about the same, 225 to 250 deg. F. apparently being the limit. In these installations the limiting steam temperature seems to be about 700 deg. F., and is generally set by the manufacturers of boilers, piping and prime movers, as it is considered that this is the limiting temperature for materials now used in standard construction.

POWDERED COAL

GREAT IMPROVEMENT has been made in the method of coal firing and powdered coal installations of considerable size have operated so successfully as to attract national attention. The efficiency obtained has been unprecedented in boiler practice, although most of those who admire this feature of the plant operation can not forget the attendant drying and grinding equipment with its apparent complexity and high operating cost. It should be needless to say, however, that the success of this equipment, particularly under peculiar fuel conditions, has placed it more strongly before engineers than ever before.

Inasmuch as the boilers, Fig. 1, installed for the Ford Motor Co., of Detroit, having a heating surface of 26,470 sq. ft. and reported to be the largest boilers in the world, are equipped with pulverized coal furnaces as well as the 13,000 sq. ft. boilers of the Milwaukee Electric Railway & Light Co., Milwaukee, Wis., it is evident that installations of this type must be given consideration in all future layouts. As a matter of fact, the boilers of many recent stoker-fired plants have been

set so that the furnaces may be later adapted to pulverized coal if it is considered advisable. The boiler shown in Fig. 1 is arranged to burn both powdered fuel and blast furnace gas. The powdered fuel enters in a downward direction as indicated just below the lower drums and the gas enters horizontally through the large nozzles lower down.

Just as the chain grate stoker remained in oblivion for years after its inception, so its successor, the forced draft chain grate, was slow in coming into its own. Its ability to burn high ash western fuels, coke breeze and lignites with proper air control and distribution throughout its various sections, has established without question, its position as a leader for this class of service, as it inherits all the advantages of its predecessor, the natural draft grate, with these additional advantages. As a result, we find an increasing number of installations with increasing areas and with increasing fuel-burning capacity per unit of area.

During the past year, grates of this type have been built in sizes heretofore thought impossible and some will soon be in operation having a total width of 24 ft. between side walls and a depth of 18 ft. from gate to bridge-wall. Many of these are so designed that they can be operated as natural draft stokers at low capacities and the forced draft feature can be added for peak service, when additional capacity is required.

By replacing the natural draft chain grates with forced draft chain grates, the capacity of many existing boiler plants has been materially increased. These installations have burned over 60 lb. of fuel per sq. ft. of grate surface per hour and in addition have successfully handled coke breeze and other low grade fuels with which the natural draft grate was a failure. This has been done, moverover, with decreased ash pit loss and increased facility of operation. See Fig. 2.

The underfeed stoker still maintains its prestige for handling coals in which the ash fusing temperature is relatively high and improvements are being continually made to increase not only the capacity of the fuel-burning area but to eliminate troubles with ash disposal, side wall clinkering and the like. The adaptability of this type of stoker to sudden changes in steam requirements, along with the high capacities which may be obtained, maintains its position and importance in the stoker field. Added to these features is that of high efficiency which has been obtained on numerous tests.

While the boilers themselves have not undergone any radical change in design or construction, there has been a steady increase in the size of the individual installations, and today a greater number of manufacturers are prepared to furnish larger boilers than ever before. While these may differ in design, it will be found that most of the standard makes compare favorably in performance as heat absorbing equipment.

Settings

THE IMPORTANCE of proper construction in the boiler settings themselves has also added to the efficiency of boiler performance. The boilers are being continually set higher above the grate surface so that more combustion space is available for the proper combustion of the fuel and its gases, while the baffling of the boilers has been so improved that draft loss through the boiler has been decreased and a maximum of surface has been exposed to the radiant heat of the furnace.

In some recent installations with powdered coal furnaces, the combustion space is over 5 cu. ft. per rated boiler horsepower, with stoker-fired installations approaching this figure very closely. This has had an effect not only on the evaporative capacity of the boiler, but has resulted in retarding the collection of clinker in the lower tubes of the first pass. Proper construction of the baffles has also reduced the amount of short circuiting of the flue gases with resultant increased efficiency.

As far as the brick work is concerned, greater care than ever before has been exercised in making the furnace brick work and the boiler setting tight in order to eliminate air infiltration. Particular ingenuity has been shown in making the joints between the boiler itself

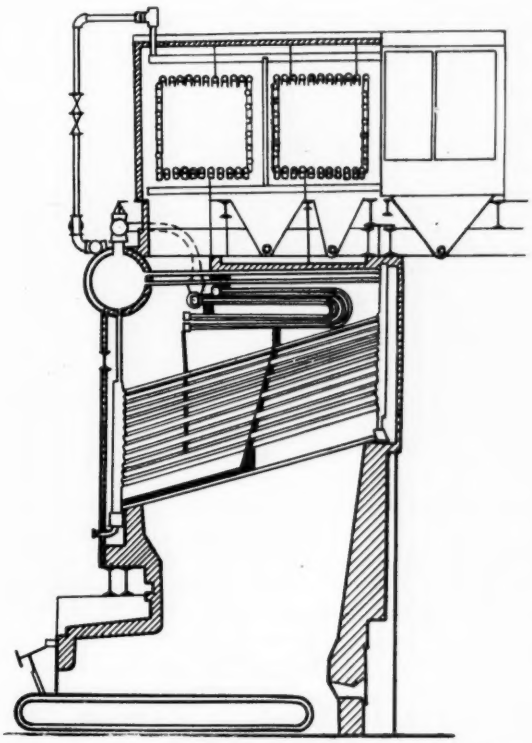


FIG. 2. BOILER WITH TRANSVERSE TUBE ECONOMIZER

and the setting and around the headers, mud drums and the like, so that air leakages of 15 per cent are today as common as those of 50 per cent a few years ago.

Contrary to common expectation, the reduction in excess air has resulted in a decrease in the uptake temperature of the boiler. While this can only be explained on the basis of radiant heat absorption, it has been borne out by tests in various large plants so that it is no longer a question. While the higher furnace temperatures resulting from the reduction of excess air have added to the furnace maintenance, in that the brick work has been destroyed faster than was customary, the increase in efficiency more than offsets any such additional maintenance cost and operators are looking to the manufacturers of firebrick and furnace linings to produce material suited to the new conditions.

Superheaters and Economizers

So far as superheaters are concerned there has been little change in design or construction, although with the advent of higher and larger boilers, it has been necessary in some cases to move the superheater closer to the fire. As a consequence, we find the superheating equipment being placed among the tubes in the first pass of certain types of boilers while in others the first pass is so sectionalized that the superheater can be placed at about the center of the first pass or sometimes even lower down as shown in Fig. 3.

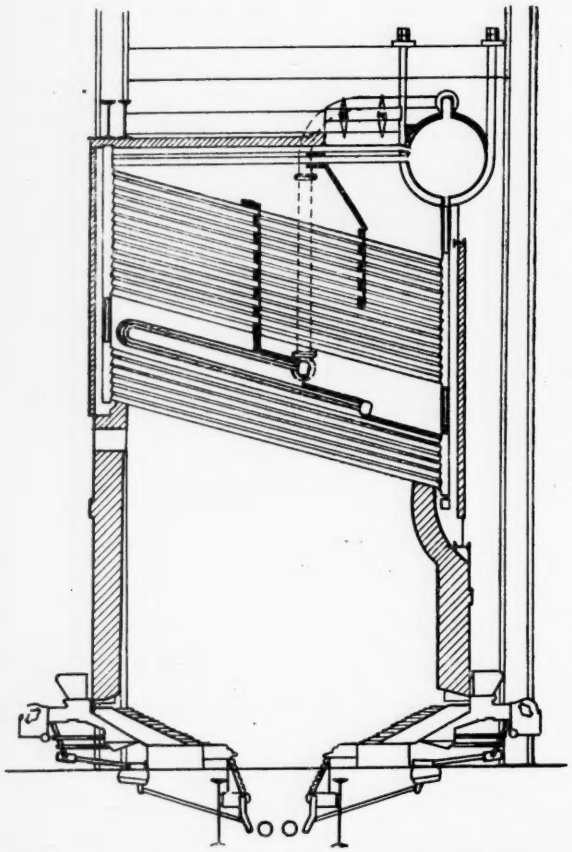


FIG. 3. BOILER WITH SUPERHEATER IN FIRST PASS BETWEEN SECTIONS OF TUBES

At times, there has been considerable discussion between boiler and turbine manufacturers regarding uniformity of superheat in the steam supply and while it is recognized that the delivery of dry steam by the boiler to the superheater is of paramount importance, recent installations have been so designed relative to superheating surface and its location, that the superheat of the steam delivered by the boiler is fairly constant regardless of capacity.

For pressure below 250 lb., cast-iron economizers continue to hold their place; but for higher pressure, the steel tube economizer is becoming standard practice. A few installations have been made with low-pressure cast-iron economizers from which the feed water is pumped into high-pressure steel economizers before entering the boiler; but such installations are rather rare, due to increased cost and the necessary complication of piping, pumps and valves. With either type of economizer, the amount of economizer surface varies with the installation and may be anywhere from 30 to 70 per cent of the boiler surface, depending upon conditions and the end to be attained.

With most cast-iron economizer installations, we find mechanical scrapers or soot blowers similar to those installed for boilers are being used for cleaning the external surface of the tubes. There are a number of installations, however, in which these surfaces are regularly washed with water with very good results; although in other cases this has been rather disastrous, as it has apparently hastened the corrosion of the tubes. With steel economizers, mechanical soot blowers seem to be the more common method of cleaning.

It is argued that from the corrosion standpoint steel economizers are more susceptible than those of cast iron, but methods have been devised for checking or at least retarding this corrosion, both external and internal, until it is no longer of prime importance. So far as external corrosion is concerned, this is dependent primarily upon the constituents of the flue gas and where the coal contains an appreciable percentage of sulphur, corrosion will be excessive at low temperatures. It has been found, however, that by raising the temperature of the feed water entering the economizer to about 140 deg. this corrosion is retarded and is almost negligible while the equipment remains in service. At the time of shutting down and starting up, however, this temperature may fall within the condensation range with the result that corrosion will take place rather rapidly for that period. With low feed water temperatures, the soot deposit on the tubes, particularly in the cold end of the economizer, becomes pasty, and so heavily laden with sulphuric acid that not only are the tubes corroded, but the clothing and the skin of the men working on the economizers are affected. This occurs with Middle West coals where the sulphur content is 4 or 5 per cent.

The internal corrosion of steel economizers due to air and gases in the feed water has been taken care of either by heating the water to the boiling point or by subjecting it to a vacuum corresponding to its temperature so that the air will be removed. In other cases where the condensate from prime movers circulates through a closed system the make-up alone is heated and de-aerated with favorable results. While emergency measures such as the placing of iron borings in the heaters and treating the water with lime have been tried, it is generally realized that the method first described must be installed for permanent results.

The use of pre-heaters for warming the air entering the furnaces has received little encouragement in this country. This is due to the low rate of heat transfer in equipment of this kind, but more to the fact that at the temperature at which this equipment would operate corrosion would take place very rapidly. While such an installation would probably reduce the uptake temperature from 100 to 150 deg. with an increase in the temperature of the incoming air nearly as great, the efficiency would soon be greatly reduced by the deposit of soot on the plates and corrosion would follow rapidly. The necessary design of this equipment precludes the use of any cleaning devices for removing the accumulation, so that with high sulphur coals particularly, it is doubtful if air preheaters would be advisable.

Feed water regulators have become standard practice, although the exactions of operators are becoming more severe. With the larger boilers the relative water storage capacity is reduced and at high rates of steaming the water level frequently becomes a matter of conjecture. The necessity for feeding water uniformly at a rate commensurate with the steaming rate of the boiler is none the less important, although it may be more difficult, as the water storage capacity of the whole system is necessarily low and any variation results in the loss of pure water with consequent make-up to follow. It is generally agreed that it would be impossible properly to regulate the feed to these boilers by hand and a mechanical regulator thus becomes a necessary adjunct.

Feed Water Preparation

Feed water preparation has increased in importance as boiler capacity has been increased, since water free from scale-forming materials and mud is absolutely necessary for the successful operation of these boilers. In modern installations where the amount of make-up is 3 or 4 per cent, the matter of condenser leakage is being given special attention, as this affords an opportunity for raw water to be mixed with the condensate without previous treating. It is therefore necessary that first of all condenser leakage be reduced to a minimum and there is no reason why leakage as low as one-half of 1 per cent of the condensate should not be obtained. In fact this will probably be recommended in the standard Test Code. For treating the make-up, evaporators have been used in many installations with considerable success, but their high cost has led to a search for a less expensive method. This has been found in water-softeners which treat the make-up in such a manner that the scale forming ingredients are removed.

Not the least important development in boiler operation has been the improvement in the status of the firemen and boiler-room engineer. The stoker operator—so-called in some instances, is coming into his own, and is being accorded the position and the pay which he deserves. Where one operator is in charge of several furnaces burning as high as 40 T. of coal per hour it is apparent, particularly with high-priced coal, that the best talent obtainable is none too good, and that the savings possible warrant a rate of pay which will compare most favorably with that for any position in the power plant.

With improved equipment, the nature of the work is entirely changed and firing nowadays is skilled work with the back-breaking features entirely removed. This work, when necessary, can be easily done by unskilled labor properly supervised. With proper instruments, a fireman can now have a complete understanding of what is going on in the furnace and throughout the boiler and with the control available can produce conditions heretofore thought impossible, except on scientific tests conducted by experts.

In the proper training of men in the art of combustion and boiler operation lies the future success of our large power producing companies and the savings may possibly represent the difference between profit and loss on the balance sheet.

Safe and Efficient Boiler Operation

Inspections, Repairs, Routine Care, Consideration of Boiler Mountings

IN THE opinion of some, inspection should be done by each shift when there is more than one shift, so that each crew may know the condition of the apparatus handed over to it as far as possible, and especially in regard to those very important matters which constitute the daily inspection.

Every safety valve should be tried, and should be provided with a cord or chain leading from the lever to the floor or platform, by which the valve may be opened. This is sometimes done by the light blow of a hammer on the lever but a steady pull is much to be preferred.

One of the first duties on entering the boiler room is to blow down the water column and note the return of water in the glass; water columns should be well lighted. If there are unlocked valves between the water column and the boiler, these should be tested for "open." Then try the gage cocks until sure of the water level, making sure the cocks are in good order and that the gage glass is clean. Gage cocks should be used frequently during the day.

In the case of boilers used for hot water heating, before starting up go to the expansion tank at the top of the building and see that water is at the correct height in the tank; then return to the boiler and make a mark on the gage at the position where the needle stands. (This can be done with red paint.) Firing should be done so as to keep the needle of the gage at this point during service. Overflow of the expansion tank should be open to the atmosphere.

Open each door to the boiler at least once a day and look for leaks at every possible point. Note tube ends, riveted seams, and blowoff piping in the furnace. Examine carefully all fire sheets for cracks, bulges, bags or blisters. In the case of a cast-iron boiler, look out particularly for cracks.

If the plant has automatic draft control and feed control these should be inspected for proper adjustment and working. The setting of all feed control valves should be examined. The attendant should make sure that draft gages are functioning properly by testing for zero reading and making sure that pipes are open.

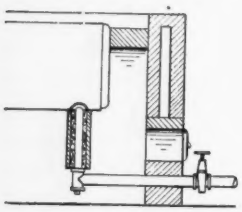
Blowing Down

Blow down one or two gages of water once or twice a day, in any case, preferably before starting up in the morning and after the noon hour. In case of dirty or chemically treated water in which much loose deposit is formed it may be necessary to blow down more frequently. The best results from blowing down are obtained when this is done after the boiler has been standing for some hours. When surface blow cocks are used they should be opened often but only for a few minutes at a time. Blowoff cocks should be opened and closed slowly in order to avoid danger from water hammer.

Insufficient blowing down is indicated by the exis-

tence of foaming, priming or scale formation. A relief for any of these is more frequent blowing down. Since these are due primarily to the condition of the water it may be possible to reduce the necessary amount of blowing down by proper treatment of the feed water.

Of course care must be taken not to blow down to a dangerous level. In water-tube boilers an element of danger is sometimes present on account of the relatively large blowoff pipe, small drum and high steam pressure. With such a combination it is possible that even with quick operation of blowoff valves the attendant would have great difficulty in properly blowing down without leaving the drum and certain tubes empty and exposed to the hot gases. In some cases this time has been found to be as short as 8 to 10 sec. Suitable sizes of blowdown connections are 1½-in. pipe for boilers up to 42 in. diameter; 2-in. up to 60 in.; and 2½-in. for larger diameters. See Figs. 1 and 2.



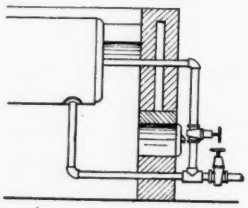


FIG. 1. BLOWOFF PIPE PROTECTED BY FIREBRICK SLEEVE
FIG. 2. BLOWOFF CONNECTION WITH CIRCULATING PIPE

It is usual to provide sufficient blowoff storage capacity so that the hot water may cool before discharge into the sewer.

Capacity of the blowoff tank may well be 1/24 the volume of the boilers, neglecting the tubes, that are to be blown down at one time.

Blowoff pipe should preferably be provided with a cock just outside the boiler setting, with a valve just beyond it. In opening to blow down, open the cock first, then the valve. In stopping the blow down, close the valve first, then the cock.

The amount of leakage at the blowoff is kept down by the use of the two valves. Owing to the severity of the service, however, the valves will leak in time. Serious leakage may be detected by feeling the temperature of the blowoff piping just outside the valves.

Soot Blowing

Soot is formed in all boiler installations and is the name given to the fine ash as well as the amorphous carbon which is carried over by the draft. It often forms as much as 15 to 20 per cent of the "ash" called for by the chemical analysis of the coal. The amount of soot increases with the intensity of the draft. The part of the soot which settles and sticks upon the heating surface has an important effect upon steaming, slowing the transfer of heat, thereby increasing the temperature of the flue gases and cutting down both the efficiency and the output of the boiler.

The rate at which soot is deposited varies with many factors, such as the temperature of the water in the boiler, temperature in furnace and tubes, kind and condition of coal, manner of firing, and rating at which the boiler is being operated. It is for this reason impossible to state how often soot blowing should be done. While heating surfaces should be kept as free from soot as practicable, soot blowing uses up steam and time and may interfere to some extent with the steaming of the boiler especially at high ratings, and may be done too often. In large plants every boiler on steady loads should be blown at least once a day, usually oftener, while the boilers which go on at peak load should be blown, if possible, after fires are bright and just before cutting in.

Soot blowing is ordinarily done by means of some form of steam jet. The steam lance cannot easily be used when the boiler is steaming. Brushes and scrapers are also effective but can be used only at certain times; they are useful during periodical inspections and cleanings.

The modern soot blower consists of nozzles so mounted that some of them create strong currents in the gas passages while others are so directed as to impinge upon certain areas which might not be cleaned by the gas currents alone. In some cleaners the nozzles are fixed in position, while in others the nozzles are so mounted that they may be moved over a certain range. Soot blowers are now designed which cover the entire surfaces effectively, but it must be borne in mind that while they remove loose soot satisfactorily they do not make much impression upon hard scale, and this must be removed by pokers.

All the ordinary precautions necessary with steam piping and valves are necessary in the operation of the soot blower. Special care should be given to drainage of the pipes to prevent the possibility of relatively cold water being thrown against the heating surfaces and brick work, and there is occasional danger of water hammer.

Few figures on the amount of steam used by steam soot blowers are available, but probably from 150 to 300 lb. per blow for a small boiler, depending upon the frequency of blowing, the care observed by the attendant, and other conditions, is a fair estimate.

Draft Control

Every boiler should be equipped with a differential draft gage placed where it can be easily seen at all times. There should be one connection to the furnace and another to the space just inside the damper. When baffles are sound and tubes are clean a fairly definite amount of draft is required to give the desired rate of combustion, and operators can soon establish this required draft. As soon as it is found that a clean fire without holes fails to respond to the draft as it should, the conclusion may be drawn that there is additional resistance due to soot on the tubes. On the other hand, if the fire responds too readily under the existing draft, it is likely that the gases are short-circuiting through holes in the baffles. If boiler is equipped with a flue gas thermometer it will be found that temperature in the flue will be higher in both cases, indicating a thermal loss.

Damper regulators are much used and are especially desirable in small plants in which the demand for steam fluctuates rapidly.

Gage Glasses

Gage glasses should be so placed that the water level may be seen and read from the operating floor. It is hardly necessary to state that they should be kept

clean and well lighted. The outside of the glass can be kept in good condition by frequent careful wiping but the inside will sooner or later become fouled sufficiently to interfere with the reading of the water level, especially if the glass is some distance from the observer. In this event it is necessary to remove the glass to clean it. Use diluted muriatic or hydrochloric acid if necessary. In cases in which the material of the glass becomes discolored, the only thing to do is to throw it away and put in new. Glasses are preferably purchased cut to length. These have ends nicely squared and are true to length.

Gage glasses are fragile and should be handled carefully. One of the most common causes of breakage is small cracks which can only be seen with difficulty. Letting the glass come in contact with metal, holding in the hand at one place, cutting with a file, or laying on an uneven surface are all causes of fracture.

A good way to cut a gage glass is with a piece of twine. Take a loop around the outside and hold a small piece of wood at the point where the glass is to be cut; fasten the twine with both ends tight and move the glass quickly back and forth along the twine. Wet the heated place a little and the glass will snap off.

As to reading the glass, it will be found that ease of reading may be greatly improved by changing the position of the artificial light if there be one, the addition of a shade, or reflector, or the placing of a background behind the glass. The color of the background can best be determined by trial.

Water Columns

The combination water column and gage glass is coming into almost universal use. Some engineers still maintain that the gage glass and water column should have independent connections to the boiler. However this may be, the water column itself should be of ample diameter so that the level of the water in it may not be too greatly affected by currents in the water and other incidental conditions. Pipes should have a cross at each bend to permit examination for scale and corrosion, and cleaning.

True readings of water level are further ensured by ample pipe connections between the water column and the boiler. A diameter of 1¼ to 1½ in. is probably a safe minimum. Large diameter of columns and piping facilitates cleaning. The Ohio State boiler law states "When shut-off valves are placed on the pipes connecting the water column to the boiler, these valves shall be of the straightway, outside screw and yoke type and shall be locked or sealed open."

In some cases the water column has been supported free from the piping. This makes the piping more secure and the piping may be disconnected at any point without disturbing the water column and the other connections.

It is important that the water column be properly located with reference to the top of the tubes, and the man in charge at every plant should know the exact level of the water column with relation to the drums and tubes in every boiler in his plant.

A good arrangement for the blowoff connection of the water column and the gage glass is to run them independently and as directly as possible to a convenient point at the front of the boiler at which globe valves are placed. Then unite the two pipes, preferably by means of a 45 deg. connection or special Y fitting and run the single pipe into the ash pit.

Gage glass and water column should be blown down several times a day. Gage cocks should be tested frequently during operation. Shealy states that it is an excellent plan to try them every 15 min. Quick-open chain-operated cocks are preferred by some engineers to those having threaded spindles because of their quick action and the ease with which they can be operated from the floor. The only objection to them seems to be that a little more attention is required to keep them in good order.

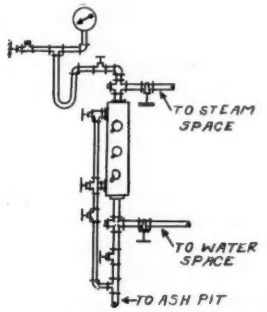


FIG. 3. FLEXIBLE ARRANGEMENT OF WATER COLUMN CONNECTION

Steam Gages

Every steam gage should be located so as to be plainly visible to boiler attendants. It should be connected preferably to the upper pipe between the boiler and the water column, and should always be provided with a siphon and a cock or valve between the siphon and the branch tee. The omission of the siphon will in time result in the hardening of the Bourdon tube and incorrect readings.

A standard or test gage or better a gage testing outfit should be found in every plant. If it is found on test that there is a practically constant difference between the readings, for instance the operating gage may be read approximately 5 lb. high over the full range of readings, this may be corrected by removing the hand of the operating gage and setting it back by the amount of difference. But if the difference in reading varies materially over the range of readings, the gage needs the attention of an expert—or it may be that it has outlived its usefulness. In changing the pointer of a gage care must be taken to lift it off the center spindle without giving it any twisting motion.

In Fig. 4 is shown a simple arrangement for testing gages by comparison with a standard gage. This may be connected permanently at some convenient point along the wall.

Safety Valves

Many authorities recommend two or more safety valves on each boiler, the combined capacity of which shall be equal to the requirements of safe blowing off. Some boiler codes specify two or more when the size required exceeds a maximum allowed diameter. In the A. S. M. E. Code the maximum single safety valve allowed is 3 in. The safety valve should preferably be

placed directly upon the boiler nozzle. In case two or more are used either a steel fitting with the necessary number of openings should be provided, or else a double or triple safety valve should be used.

It is a good plan to have a safety valve so arranged that when the disc is raised to try out the valve, the man doing this may watch the pressure gage and the gage glass. Any unusual disturbance in the water level or steam pressure may indicate that priming or foaming is taking place due to the rapid outflow of steam.

Some authorities favor the use of a small safety valve to be set at a pressure 2 or 3 lb. less than the pressure at which the main valves are set, which shall act as a sort of signal to warn the operators that the main valves may be expected soon to blow. Most authorities are strongly of the opinion that the discharge from each safety valve should be led away from the boiler room.

There seems to be an economical advantage in the use of more than one safety valve on a single boiler. It lies in the amount of steam blown off. A certain boiler operating under 100-lb. steam pressure may be equipped with one 4½-in. safety valve or two 2½-in. When popping, the larger valve discharges 72 lb. of steam in 30 sec. The smaller valve discharges 40 lb. of steam in 30 sec. Assuming the same duration of blowing, which would likely be true with proper attendance, there would be a saving of steam of 32 lb. at each pop. It should be stated that when two or more safety valves are used they should be set with a small difference in their popping pressures.

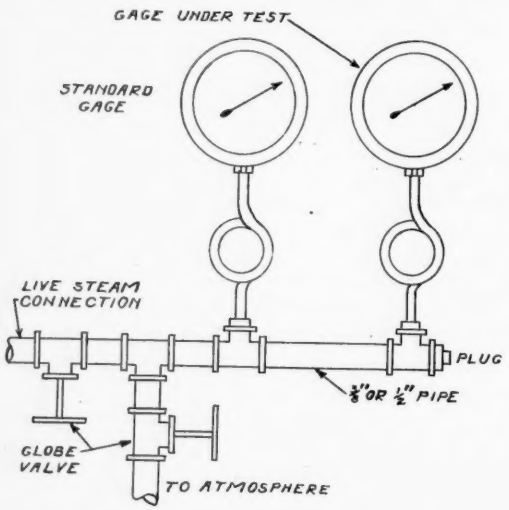


FIG. 4. ARRANGEMENT FOR TESTING STEAM GAGES

Safety valves should be kept steam tight. A leaky safety valve may waste a surprisingly large amount of steam; also the blowing of steam through a leaky safety valve cuts the surfaces so that the leakage grows worse more and more rapidly. It follows, therefore, that a leak of this sort should be taken care of at once. Before resurfacing is undertaken, a careful examination should be made to make sure that no foreign matter sticks upon the surface, which prevents the proper closing of the valve. The smaller the valve the easier it is to keep it right.

Leaks may be due to the distortion of the valve seat. Bolts may be tightened unequally or the weight of blow back piping may be the cause. In some cases it has been found advisable to support the blowback piping independently and connect it to the valve by a slip joint. Small imperfections in the valve can be removed by grinding.

Safety valves should be tested occasionally by raising the boiler pressure to the blowing-off pressure. In the opinion of some authorities this should be done not less frequently than twice a week.

Foaming and Priming

Water is sometimes carried with the steam up through the water to the surface and may fill the entire steam space. In this case the discharge from the boiler is largely made up of small steam bubbles which become separated into steam and water in the steam pipes. This is called priming, and is caused by contracted water space, insufficient steam liberating surface, poor design or overcrowding boiler.

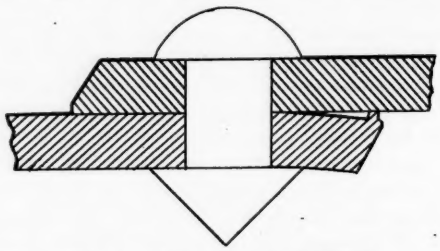


FIG. 5. GOOD AND BAD CALKING

Attendants may carelessly let the water level rise to such a high point that the steaming space and in some cases the steam liberating surface will be unduly contracted. A boiler may supply dry steam when not overworked, and yet may prime heavily when it is hard pressed.

Foaming is due to suspended impurities which form a scum on the surface of the water which foams as the steam is formed. Since foaming is caused by the condition of the water it may take place in any boiler.

Priming results in wetter steam than does foaming.

If either foaming or priming is especially violent the draft should be shut off at once and the fires covered until the cause can be removed.

Surface blowing and blowing down are the most effective cures for foaming. Foaming may become so troublesome that change in the water treatment even to the extent of installing new equipment may be necessary. Oil and suspended matter must be kept out and careful filtering alone may be effective.

Both foaming and priming may be reduced by cutting down the steaming rate. Permanent improvement may often be made by the installation of dry pans or dry pipes or baffles in the steaming space which act in the nature of separators. The changing of the steam connection from one nozzle on the boiler to another has been known to improve this condition.

In some cases when the required amount of steam is fixed, especially when priming is troublesome, the most effective and really the only solution is to work more boiler capacity and thus reduce the rate of steaming.

Stopping Leaks

The general rule may be laid down that no attempt should be made to stop leaks while the boiler is under steam pressure. All leaks should be called to the attention of chief, who, in important cases, will do well to call an inspector or competent boiler maker. Note should be made of the exact position of a leak at the time it is discovered, and a mark should be put upon the place of the leak itself. Leaky seams and rivets and leaks about nozzles can usually be made tight by calking. Leaky joints due to the presence of oil in the water can only be prevented by keeping the oil out of the boiler. In any case the cause of a leak should be found and removed.

The ring seam over the fire in the case of horizontal tubular boilers usually shows a much more rapid deterioration than any other part of the boiler. A combination of the conditions of rolling (both in the orignal manufacture of the plate and in the forming of the plates in the boiler shop), the high temperature of the metal due to the double thickness, and the local pressure due to the driving of the rivet may result in so bad a condition that patching may be necessary. Before resorting to patching, however, calking may be tried around the rivet and in other places where the steam may get through. Cracks often form extending from the rivet to the edge of the plate, and while these are often troublesome they are not usually dangerous unless the crack extends inside from the rivet. If calking is not effective, a patch may become necessary. The form of the brick setting is sometimes responsible for rapid deterioration and some slight change may be made in it to improve these conditions. Before any patching is undertaken careful examination should be given to the question: "Is it worth while?"

Calking should always be done with a round pointed tool. A square or sharp tool is liable to injure the plates by forming a slight groove which may increase

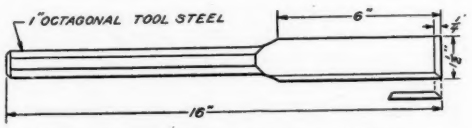


FIG. 6. RIPPER FOR REMOVING TUBES

rapidly by corrosion and by working of the plates under expansion and contraction. Heads of leaky rivets may be made tight by calking around with a round pointed tool. Opposite head of rivet should be supported if possible while calking is being done. Good and bad calking are shown in Fig. 5.

Patching

Of all boiler troubles in connection with repairs patching is the last resort.

A soft patch is always a temporary repair and derives its name from the fact that a rubber gasket or cement is employed to make a tight joint between the patch and the defective plate. The edges of the plate are not calked. It is in reality a packed flange joint. A soft patch should never be made where it will come in direct contact with the products of combustion, consequently is not feasible except upon the external shell of internally fired boilers or above the fire line in the steam space of horizontal tubular and water-tube boilers.

To make a soft patch, cut out the defective part of the plate; secure a piece of boiler plate of suitable thickness and quality, then cut it to proper size and bend with care so as to make a good fit upon the plate to be patched. Secure with the proper number of cap screws or through bolts. Cap screws should not be used unless the thickness of plate is sufficient to secure full threads and a good hold. If possible, holes should be drilled through both plates in place and through bolts used. A large opening should not be closed with a soft patch. For small patches the pitch and size of bolts may ordinarily be made the same as those of rivets

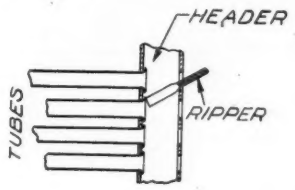


FIG. 7. RIGHT METHOD OF USING RIPPER

found around manhole rings in the boiler being patched. Lap should be generous, a lap of three diameters being sometimes recommended.

A hard patch in distinction from a soft patch may be considered in the nature of a permanent repair. No gasket is used and the patch is riveted on and calked in a manner to make the job as nearly perfect as possible. A patch properly applied should in no way detract from the useful service of a boiler, unless in the rather extreme case that it makes it necessary to operate the boiler at reduced pressure. The advice of a competent boiler maker or inspector should be asked and followed, both as to feasibility of patching and as to the layout of the patch. In patching, the formation of troublesome pockets must be avoided and provision made for properly securing any staying that may interfere.

Retubing

In a fire-tube boiler the location of the tube will govern, to some extent, the procedure in getting the tube out. If the tube is located so that it can be taken out of the lower manhole, it can be cut off at one end, just inside the head, with a bent chisel, and the short piece of tube ripped through the seat with the ripper.

The ripper is a plain, simple tool for the quick removal of a tube. Figure 6 shows how the tool is made and Fig. 7 the right method of use in a water-tube boiler. The ripper is shown with a beveled point. Sometimes this edge is left square. The header cap opposite the tube is removed, also a cap above or below and the ripper started at an angle with the tube. If the ripper cannot be set at an angle, the edge of the tube should be turned up with a heavy steel bar (say 1¾ in. in diameter by 3 to 5 ft. long) before starting the ripper. This bar may be used to collapse the tube after the ripper has made the cut.

The easiest way to remove a tube from the bottom is to rip and collapse the ends, then cut the tube in pieces and remove it through the fire door. The inside

cutter is best for this purpose, but an ordinary pipe cutter will do.

Tubes that cannot be taken out at the manhole must come through the tube hole. As tubes are usually covered with scale it may save time to run the tube cleaner through the tubes to knock off all scale possible before cutting. Hammering the tube close to the header will help to loosen the scale. When the tube is to come through the tube hole the ends are ripped and closed up. It may be driven out a few feet with a sledge hammer and block of hard wood, but it cannot be driven far in this manner. It may be possible to get a flat bar down between the tubes from the top and drive the tube out with it. It is usually easier to pull it

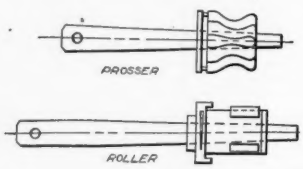


FIG. 8. WEDGE AND ROLLER EXPANDERS

out with a chain hoist. It will come still easier if twisted with a pipe wrench while pulling. As the back end will be battered up it may be necessary to close it up with a hammer and chisel.

As more damage may easily be done to the tube seats in taking out old tubes than from operating the boiler several years, it should be done with especial care.

After removing the tube, the seat should be cleaned and a new tube slipped in. Some engineers recommend annealing the ends of new tubes, by heating to a dull red in a charcoal fire and cooling slowly to make them more homogeneous, and to prevent them from cracking while being expanded and beaded. This is not necessary, if the tube is of proper diameter and length. Two forms of expanders are shown in Fig. 8. The tubes

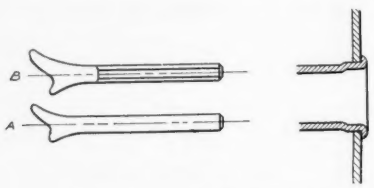


FIG. 9. BEADING TOOLS
FIG. 10. BEADED TUBE END

of fire-tube boilers should project through the sheet about ⅜ in. on each end. If they extend through more than this they may be cracked in beading. See that ends extend through the proper distance and then have a helper hold the front end from slipping by means of a bar while the rear end is being rolled.

The expander should be set to extend the same distance each side of the sheet and the tube should be expanded gradually all around to prevent splitting.

A tube may be rolled too much and thus be made excessively thin at the seat. When a tube is rolled out tight all around, the rolls will be running on a smooth surface, and the plug will be tight when tapped with the hammer. It is best to stop at this time and examine and if there are any spots that are not rolled out tight against the seat, further rolling should be done.

The ends should next be beaded by means of a beading tool such as is shown in Fig. 9. The bit of these tools is about ⅜ in. wide. Tool B is used to draw the edge over, striking lightly to prevent splitting, and working clear around the end, while tool A is used to draw it down flat against the sheet. Figure 10 shows how a rolled and beaded tube should look.

Whenever tubes have been replaced an hydraulic test should be made to determine whether the work has been properly done.

Feed System

Although the feed system is in many ways one of the simplest features of the boiler plant, it probably gives as much trouble as almost any other part of the piping. There seems to be no uniform practice in regard to size, material, and arrangement of the feed system. Regardless of all precautions they may occasionally be subject to pressures as much as 50 per cent greater than

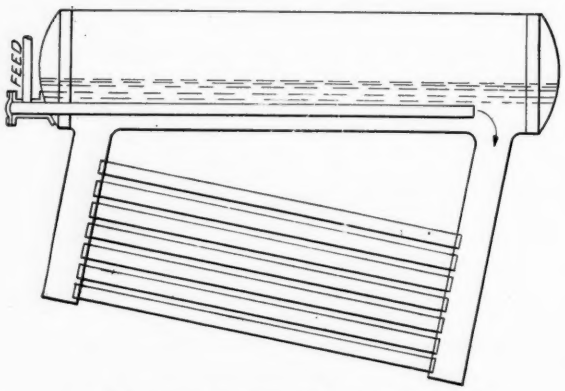


FIG. 11. FEED PIPE CONNECTION TO BOILER

that in the boilers. Extra heavy pipe is commonly used especially when the pressure runs above 125 lb. sq. in.

Iron pipe is commonly used when the temperature does not exceed 200 deg. and when water is given proper chemical treatment before entering the pipe. If water comes from an open heater it will not pit iron pipe but it may deposit some scale. When it is known that the water deposits scale corrosion need not be feared. Smooth iron pipe, such as seamless drawn tubing gives little trouble with scale. If the water corrodes iron pipe, brass tubing of the same diameter may be used.

It is advisable to put a valve on each side of the check valve to facilitate repairs of the latter. Globe valves should be placed with stems horizontal as far as possible and flow from the underside of the disc.

An interesting suggestion worth trying when scale is troublesome is the placing of a pressure gage in the feed line some distance from the boiler, this gage to be used in connection with the boiler gage to determine the increasing resistance to flow due to the accumulation of scale in the feed pipe.

The pipe into the boiler should have its opening considerably below the water level. Figure 11 shows an arrangement in which the water is delivered into the

coldest part of the boiler and which can easily be cleaned.

The feed piping should be covered and covering should be kept in good repair.

In order to keep the water level in the boiler as nearly constant as possible feed-water regulators are sometimes used.

Baffles

Sometimes boilers give high efficiency when they are new and the baffling is in good condition, but after they are used a while and it becomes necessary to replace tubes, the baffling is partially wrecked in the process and the hot gases short-circuited through the broken baffling.

A lowering of the draft drop between the furnace and the damper often indicates the presence of holes in the baffles. These holes allow the gases to short-circuit which raises the flue temperature and cuts down efficiency. To inspect the baffles put a man on top of the tubes and one below, one holding a lamp, the other observing. Inspect every inch of baffle surface. The renewing and warping of tubes and side wall settlement usually cause cracks and holes. Particular attention should be given to the space between the bottom and first flame plate and the top of the bridge wall in vertically baffled boilers. Holes at this point are most serious.

Small holes and cracks may ordinarily be filled with fire clay or plastic lining material. Small loose pieces should be removed and whole tile fitted in with high temperature cement or fire clay.

The baffles control the flow of gases in water-tube boilers to a large extent, hence their arrangement has an important bearing on the operation of the boiler

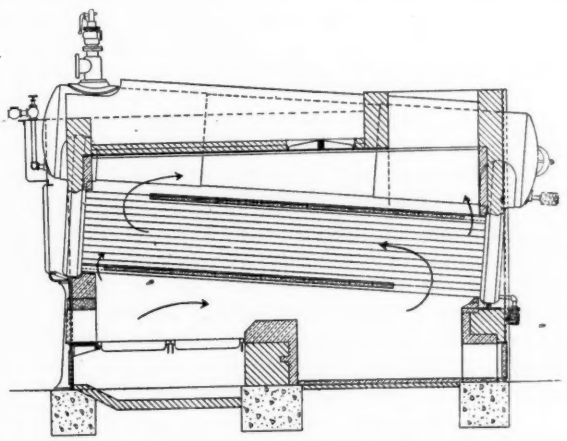


FIG. 12. WATER TUBE BOILER ARRANGED WITH HORIZONTAL BAFFLING

and furnace. It is often found that operation may be materially improved by making changes in the position and extent of the baffling. Horizontal and vertical baffling are shown in Figs. 12 and 13.

The following method for improving the tightness of baffles and prolonging their life proved effective in a vertically baffled horizontal water-tube boiler. The baffle between the first and second pass had a layer of brick on one side of it. That between the second and third passes had asbestos and cement plastered on both sides of it but no brick. A coating, 1 to 2 in. thick, made of 1 bag of hot glass cement mixed with 8 qt. of ground firebrick and 4 qt. of Portland cement, was plastered on both sides of rear baffle and on the front side of front baffle by means of a long-handled paddle. In making this plaster just enough water was added to make a plastic mixture. An inspection 4 or 5 months after applying showed that the tubes were perfectly

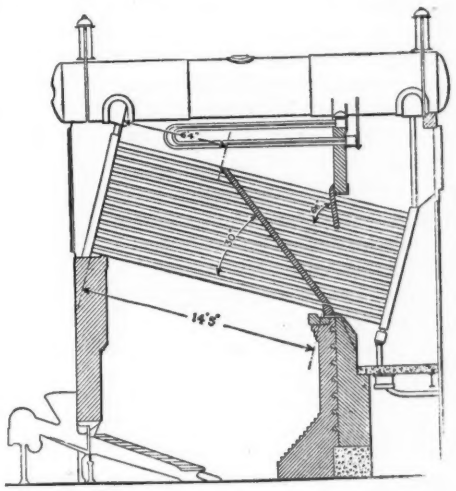


FIG. 13. WATER TUBE BOILER ARRANGED WITH VERTICAL BAFFLING

tight and that turbining the tubes does not loosen them away from the baffles.

Monthly Inspection

Properly conducted periodical inspections of the character about to be described are advisable for reasons of safety, economy of operation, and proper control of maintenance costs. In this connection it might be stated that too much reliance ought not to be made upon the yearly inspection, that is, each periodical inspection should be complete in itself.

Each boiler should be withdrawn from service at least once each month for inspection. Local conditions may make it necessary to perform this inspection more frequently. In extreme cases it may be necessary to clean them as often as once a week. Frequency can, however, only be decided upon by the conditions prevailing in each individual case. It has sometimes been found advisable to clean more frequently in dry seasons than in wet seasons, due to the fact that at such times the water can carry more foreign matter.

In cooling down, close valve between boiler and steam header; close the feed valve and draw the fire. When pressure has dropped to 10 lb. or less, open the blowoff and empty the boiler. Remove all soot and ashes possible and allow the brick work to cool. Then remove the manhole cover; it is a good plan to scratch cover and manhole seats in such a manner as to make it possible to put the cover back in the same position. This often saves the cutting of a new gasket.

Careful record should be kept of every inspection made. As soon as the boiler and brick work are well cooled down boilers should be thoroughly washed out. A large part of the loose sediment may be removed by washing by means of a hose throwing a strong stream

of water which should be directed against all parts of the boiler from every direction possible. If sufficient time cannot be allowed for the boiler to cool, hot water should be used for washing.

The inside of the boiler should be examined for scale. Is there any? Is it hard or soft, loose or adhering Where accumulated and where in greatest amount? Examine carefully, also, for pitting and corrosion, especially near the water level, although this may occur anywhere inside the boiler. Examine also for oil. If any tubes appear to be in a dangerous condition they should be replaced at once. It may save time to remember that, in water-tube boilers, "if there is no scale in the lower row of tubes there is probably none in the rest." Do not fail to give careful attention to the feed water lines at the entrance to the boiler. These are usually found to contain a great deal of scale, sometimes in sufficient quantity to interfere seriously with the flow. The piping to the water column should also be examined to make certain that the openings are not clogged.

In boilers having stays, it is necessary to test for tightness of stay rivets. In particular examine the stays for looseness, as it is likely that a loose stay is not carrying its share of the load. To test a rivet for tightness, place thumb or finger of left hand so as to rest against rivet head and surface around it. Hit rivet with hammer. Any relative motion of rivet and plate will be felt.

In examining the exterior of the boiler, give particular attention to the tubes, especially those in locations where soot and dust collect and at which corrosion may take place. Such corrosion is often caused by water which leaks from the boiler and mingles with this dust, and can only be prevented by preventing the leakage.

Particular attention should be given to the blowoff connections and piping to make sure that no rapid deterioration is taking place in the metal. In those cases in which the blowoff pipe is protected from the fire by special covering or brick work, such covering or brick work should be examined for cracks or crumbling away. The presence of mud deposit in the mud drum indicates that it is not blown out often enough.

Cleaning

A boiler is prepared for cleaning in the same manner as already described under inspection.

The tubes may be readily cleaned of soot by means of a round wire brush or scraper. All remaining ashes may then be removed from the grates after which interior brickwork, furnace linings and the shell should be brushed with flat wire brushes. All manhole and handhole plates may now be removed and any scale found on these plates may be scraped off or, if the scale is soft, washed off.

The shell should be well washed out with hose and water, water and loose scale draining out at the blowoff. The boiler may now be entered and by means of a scraper somewhat wider than a putty knife all scale may usually be removed. When scale is extremely hard it will be necessary to use a cold chisel and hammer.

Every part of the interior surface should be carefully gone over, care being taken not to damage the plates.

In boilers having horizontal or slightly inclined tubes the usual procedure, after the boiler is cooled down and empty, is to remove the manhole plates in the drums and wash out. Next remove all handhole plates in the headers and clean tubes. The drums may be treated the same as the shells of tubular boilers. Hard scale in straight tubes of water-tube boilers is usually drilled out by means of one of the various forms of tube cleaners on the market. Inclined boiler tubes are usually drilled from the front end to the rear which allows more room for operating the cleaner and permits the scale to pass more readily into the rear header. The front and rear tube sheets and handhole plates should next be scraped and handhole plates replaced, and the boiler again thoroughly washed out.

Before replacing handhole and manhole plates the condition of the gaskets should be examined and new ones put in if necessary. Good packings and manhole and handhole gaskets are on the market or they may be made of sheet or molded lead.

In the case of boilers having bent tubes between drums, it is necessary to enter the drums to operate the drill, otherwise the procedure is the same as for other types.

If water is good or if water treatment is correct and if the boiler has been kept in good condition by frequent cleanings, the deposit of scale should be small with little or no pitting and corrosion, and the physical treatment suggested above will be adequate. But if not it may be necessary to use one or both of the following methods.

Kerosene is often quite effective. It will not penetrate wet scale to advantage, but when the scale is dry the kerosene works in between the scale and the metal and causes the two to separate. To apply the kerosene properly the boiler should be emptied and allowed to stand until the heat from the setting has dried out the scale. The kerosene should then be sprayed into the boiler in generous quantities so that every part where scale may be lodged shall become thoroughly drenched. Upon standing for a time after this, striking on the boiler and tubes with a hammer or bar will knock off the scale in large quantities.

Next give the boiler an especially thorough cleaning by scraping or chipping the scale from every accessible part and washing out again with special care.

Deposits of hard, stony scale in the tubes of water-tube boilers may be loosened by soaking them, when dry, with kerosene, applied by a mop. When this is done the boiler should be cleaned soon again.

Kerosene should never be used unless the operation is directed by a man thoroughly familiar with the dangers involved. It should only be used in any case as a last resort when other means have been faithfully tried and found to be ineffective. Kerosene should never be used for spraying, scrubbing out, or in any other way—*while other boilers in the same room are in service.*

it is sometimes desirable to clean it by "boiling out." In this process the boiler is filled with water to a level higher than the scale deposit, and a liberal amount of soda ash added. The quantity of soda ash required depends upon the size and condition of the boiler. For a 72-in. horizontal tubular boiler 30 or 40 lb. may often

be necessary. The effectiveness of the treatment is increased by adding to the soda ash about one-tenth of its weight of caustic soda. Many engineers also favor adding two or three gallons of kerosene oil. The soda ash—and the caustic soda, if it is used—should be dissolved before it is put into the boiler.

When the boiler has been filled and the soda ash and other constituents have been introduced, a slow fire should be built in the furnace and kept up for two or three days, and regulated to keep the water boiling gently. The manhole should always be left open, so that no steam pressure can accumulate in the boiler, or the same end should be accomplished in some other equally effective way. If caustic soda or kerosene is used, the precautions given here should be carefully observed.

After the boiler has been treated as just described, it should be emptied and washed out with a hose; and if kerosene has been used, the boiler should also be thoroughly ventilated before bringing an open light near it, or entering. Avoid the use of kerosene in "boiling out" operations whenever possible, especially when the oil-vapor must escape into the boiler room, for there is always a chance that this vapor will take fire at one of the furnaces, or in some other way. If kerosene is used a duct should be provided to conduct the vapor from the manhole to the outer air, without permitting it to escape into the boiler room.

After the boiler has been emptied, washed and ventilated, the entire interior should be thoroughly cleaned by hand tools and in other ways. All loose scale must next be washed out.

Corrosion and Pitting

These are caused by chemical action on the metal of the boiler. The remedy for exterior corrosion is to keep the surfaces free from dust and moisture. When there is considerable corrosion the effect on the tubes is hard to determine and it may be necessary to remove one or more of them for detailed examination. To determine the depth of corrosion in drums or shells it is sometimes necessary to drill holes through the plate. These can be sealed by means of rivets.

The trouble may be due to absorbed air, which is commonly the case when returns are collected and used again. Air bubbles form below the water line and the oxygen of the air attacks the metal, leaving minute pits which enlarge under further action. Both general corrosion and pitting may be reduced or even eliminated by using an open feed water heater, which expels the air or, better still, by a feed water heater connected to a vacuum pump.

Corrosion may be due to the presence of acids. If a fair sample of the water turns blue litmus paper red there is acid present. In this case the water may be neutralized by the addition of the carbonate of soda to the point that the water will just turn red litmus paper blue. By using only the highest grades of hydrocarbon (mineral) oils acidity may be prevented in many cases.

The damage done by pitting and corrosion may be so serious that it is advisable to consult a chemist when there is any question as to the proper method to follow.

Mud Drums

A mud drum is a receptacle provided to collect mud and sediment which may be brought in by the feed water, usually before it goes into circulation in the boiler. They are of value when the water contains heavy sediment in mechanical suspension and only when they are placed at a point where the convection currents are quite slow.

At the present time mud drums are used almost exclusively in connection with water-tube boilers.

Owing to the fact that the circulation in the mud drum may be extremely sluggish it should not be exposed to the direct heat of the fire, since it may become burned and thus be a source of danger.

The mud drum should be blown off at intervals to keep it in condition to receive sediment.

Water Treatment

For the proper chemical treatment of boiler feed water it is necessary to make frequent analyses and to prepare the treatment accordingly. This is especially true when surface water from lakes, rivers and creeks is subject to decided changes. Boiler water may be treated either by the addition of boiler compounds in which case the treatment generally takes place in the boiler or by purifying plants in which the water is purified before it enters the boiler.

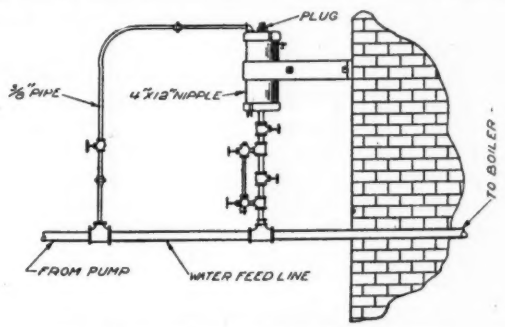


FIG. 14. FEEDER FOR BOILER COMPOUND

Boiler compounds may be divided into three classes:

1. Those substances which convert the scale-forming elements into new substances which do not form hard, resisting scale and which may readily be removed by skimming, blowing off, or mechanical tube cleaners.

2. Those substances such as starches, woody fibers, dextrine, slippery elm, etc., which envelop the newly precipitated scale-forming crystals with a surface which prevents them from cementing together.

3. Those substances which prevent the formation of hard scale by causing a solvent or rotting action such as kerosene and petroleum oils. These are usually fed to the boiler drop by drop by sight feed apparatus and sometimes give good results, but are not used extensively.

Boiler compounds give best results when introduced continuously or at short intervals. In Fig. 14 is shown a simple form of feeder.

Water softening consists in the removal of those insoluble mineral compounds which cause hardness before the water enters the boiler. These ingredients are removed by adding to the water chemicals which react with the hardening substances, thus changing them into insoluble compounds which may readily be separated from the water. The chemicals generally used for softening water are quicklime, soda ash, caustic soda, and trisodium phosphate.

The zeolite process is one of comparatively recent development. Zeolite, the softening agent, is an artificial material which is composed largely of sodium compounds. It is packed in a cylinder and the hard water made to flow through it. During this flowing process which brings the water into intimate contact with the zeolite the scale-forming material in the water is exchanged for the sodium compounds in the zeolite and the water leaves the cylinder with all scale-forming material removed. The water is, however, charged with an equivalent amount of sodium salt, but foaming is prevented by removing this sodium salt through the blowoff.

The amount of blowing down may be reduced by introducing lime into the water before the water is passed over the zeolite. A filter is placed between the tank in which the lime is introduced and the zeolite to prevent the sludge resulting from the introduction of the lime from coming in contact with the zeolite and coating the particles, thereby impairing its action. .

The zeolite bed can be used again and again indefinitely. The zeolite is regenerated or brought back to its original state by passing a solution of common salt through the bed in a direction opposite to that of the hard water, and a reverse of the softening exchange takes place; the calcium and magnesium previously absorbed from the hard water are replaced by sodium, and the calcium and magnesium are discharged to the sewer in solution.

Mechanical Prevention of Scale

The action of graphite in the boiler is not of a chemical nature. The particles of graphite work through the minute fissures which exist in the scale and gradually penetrate into the space between the scale and the metal. As a result of this the scale is loosened and may be removed with the regular cleaning tools. The penetration and loosening may, in the case of scale which is very hard and thick, take as long as 3 to 4 mo. When once the scale is removed, a continuation of the graphite treatment will prevent further scale from adhering firmly to the metal.

Very finely ground graphite of good quality is usually advised for this purpose. On beginning the graphite treatment the quantity suggested is about ½ lb. per day of 12 hr. for each 250 hp. of boiler. Less may be used after boilers are clean. Mix the graphite thoroughly into hot water and introduce it through the pump suction after blowing down two gages. In a battery of boilers particular care should be taken that each boiler is fed its proper proportion of the graphite.

Mechanical filtration is effective in removing all foreign matter which is not in solution or in chemical combination with the water. Coke, cloth, excelsior, fine gauze or the like are commonly used. Continuity of operation is made possible by duplicate filters. Mud and sand will gravitate out if the water is allowed to stand in settling tanks.

Zinc is sometimes placed in the boiler to prevent corrosion when sea water gives trouble. It must be in perfect electrical connection with the metal of the boiler, be located below the surface of the water and be provided with a steel basket to catch the disintegrated zinc. One square inch of zinc surface takes care of about 50 lb. of water in the boiler though the amount necessarily depends upon the hardness.

Yearly Overhauling—Laying Up

Once every year at least every steam boiler should be given a complete overhauling. Boiler should be cleaned and prepared for inspection as already described under monthly inspection. Safety valve and steam gages should be carefully tested. It is sometimes best, if time will permit, to send them to the manufacturers for testing and going over. Water column, feed piping, and blow out piping are opened up and such pipes and fittings as are badly corroded or clogged are either thoroughly cleaned or replaced. Valves are overhauled and replaced when necessary. The same may be said of boiler tubes. Water leg and mud drum should be given thorough cleaning at this time.

Usually the annual official inspection is made at this time and much of the work forming part of the general overhauling conforms to the suggestions and in some instances the explicit orders of the inspector. All recommendations made by the inspector should be carefully noted and they should be carried out faithfully whether they relate to the boiler or to accessory apparatus of any kind.

Repairs should always be carefully executed and makeshift methods should never be tolerated. *Repairs, whether trivial or serious, should never be made upon a boiler, pipe or other vessel while it is under pressure.*

When a boiler is to be put out of service for a considerable period of time, it should be emptied and every accessible part, both inside and outside, should be thoroughly cleaned. All soot should be scrupulously cleaned from the external surfaces because after a time the soot is likely to become damp due to moisture from the air, and corrosion is almost sure to follow. The tubes should be carefully cleaned and all deposits of dust and ashes removed from the furnace, combustion chamber, and setting, both inside and outside. Scale and other deposits should be removed as completely as possible, and the boiler should be thoroughly washed out. Any water that remains can be removed by mopping or, as some engineers advocate, by a light fire in the furnace of paper or other loose material. This is not advised since there is danger that the attendant may build too brisk a fire and damage the boiler. The manhole and handhole plates should be left off to allow air to circulate freely through all parts of the boiler. If this is done the interior will dry out without special heat, and if the boiler is in a battery in operation it will dry rapidly.

The steam and water connections to the boiler must be closed perfectly tight to keep moisture from leaking into the boiler while it is laid up. As a precaution against corrosion it is a good plan to place a small quantity of unslaked lime inside the boiler. Boilers which lie idle during certain parts of the year should be cleaned and dried with special care each time they are put out of service.

After being laid up the boiler should be carefully examined to see if it needs repairs. Any repairs found necessary should be made immediately, so that in case of emergency the boiler can be restored to service without delay.

Care and Operation of Boiler Furnaces

ESSENTIALS FOR PERFECT COMBUSTION; METHODS OF FIRING AND COMBUSTION CONTROL; BOILER SETTINGS AND THEIR REPAIR

FURNACES SHOULD be designed so far as possible for the particular coal which is to be burned in them, and where furnaces have been so designed a change in fuel may make changes in the furnace necessary.

It was found at the fuel testing plant of the U. S. Geological Survey that the average time taken by the gases to pass through the combustion chamber of an ordinary furnace is 1 sec., which means a velocity of from about 10 to about 20 ft. per sec. Since a flame travels through a perfect mixture of explosive gas at the rate of 1000 ft. per sec., it seems apparent that with proper mixing at high temperature complete combustion is reasonably to be expected in a furnace at the low velocities just stated.

With anthracite coal, due to the fact that the fuel is virtually all consumed close to the grate, the volume of the combustion space may be relatively small, and grates are sometimes placed as close as 2 to 3 ft. below the boiler in horizontal tubular settings. With other coals, it is necessary to give relatively large volume to provide combustion space and mixing space for the large volumes of gas generated which often run as high as 35 per cent of the weight of the coal. This may be done by building the furnace high, or out in front of the boiler in some form of Dutch oven, or by providing space behind the bridge wall. This large volume is made necessary by the fact that the distilled gases rise quickly from the solid remaining portion of the coal and must be mixed with air entering above or behind the grate and be consumed at a high temperature before being chilled to any extent by the boiler surfaces.

One boiler company which has been developing large furnaces has had good results with from 3 to 4½ cu. ft. per rated horsepower. These recommendations are for Western Pennsylvania coals.

If due to change of fuel or some other reason the existing combustion space proves to be too small, it may be worth while to go to the expense of resetting the boiler. This is usually not warranted and in many cases would not be possible. In one case it helped matters to change the baffling on cross-baffled boilers to horizontal baffles, to lower the bridge wall, thus making the space back of the bridge wall available for combustion, and to build piers and wing walls to mix the gases. The results were beneficial so far as abatement of smoke and improved combustion were concerned, but there was difficulty in keeping the surface of all tubes clean and in keeping the additional brickwork in repair.

Tests made upon a horizontally baffled water-tube boiler and a special side-feed stoker gave results as shown in Fig. 1. These figures can be used as a guide in designing or changing almost any style of furnace. A long narrow combustion space is to be favored rather than a short wide one of the same cubical contents. For boilers operated at heavy overloads, a large furnace volume is particularly essential. Efficient combustion is secured when the furnace volume permits ample time, adequate mixing, and sufficient temperature for thorough burning of the gases and exists when just enough space is provided to permit complete combustion before the products of combustion go into the tube spaces. There should be a regular movement of gases with a minimum of eddying and surging. There is in general less loss from furnaces that are too large than from those that are too small.

GRATES

THE ORDINARY rates at which coal is consumed, expressed in pounds per square foot of grate area per hour, are as follows:

With chimney draft:	
Anthracite	15- 20
Bituminous	20- 25
With forced draft:	
Stationary water-tube boilers	25- 50
Locomotives	40-100
Torpedo boats	60-125

The amount of coal which can be burned is governed by the character of coal and the available draft.

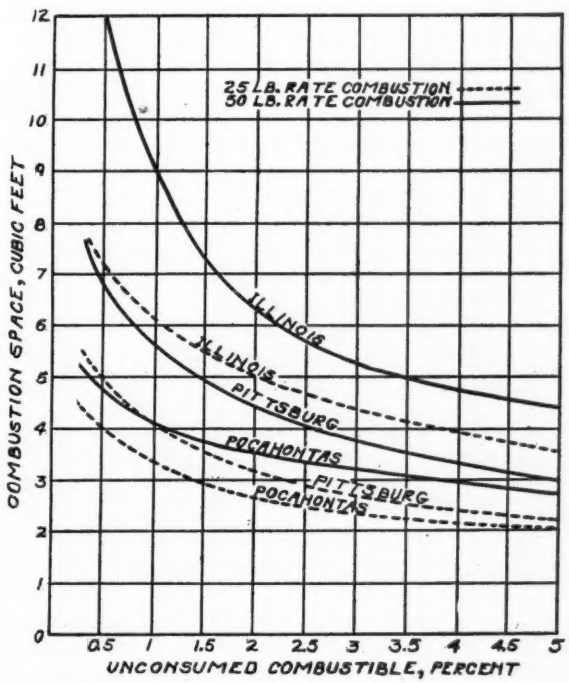


FIG. 1. COMBUSTION VOLUME PER SQUARE FOOT OF GRATE SURFACE FOR VARIOUS COALS

The curves in Fig. 2 give the combustion rates resulting from the drafts indicated for general condition. Curve No. 1 is for anthracite buckwheat No. 3; No. 2, anthracite buckwheat No. 1; No. 3, anthracite pea; No. 4, bituminous slack on chain grate; No. 5, run of mine, semi-bituminous; No. 6, bituminous slack, and No. 7, run of mine, bituminous. These curves are based upon

the results of numerous tests with various coals and allow a safe margin for economical burning.

TABLE I. WIDTH OF BARS AND AIR SPACES

Kind of fuel	Width air space, in.	Thickness iron, in.
Screenings	1/4	3/8
Buckwheat	3/8	3/8
Nut or pea	1/2	1/2
Bituminous or stove	5/8	1/2
Egg	3/4	1/2
Broken	7/8	1/2
Lump	1	1/2
Sawdust	1/4 or 3/8	3/8
Shavings	1/2 or 5/8	1/2

Air spaces through grates should be as large as the grade of fuel will permit. With anthracite slack the

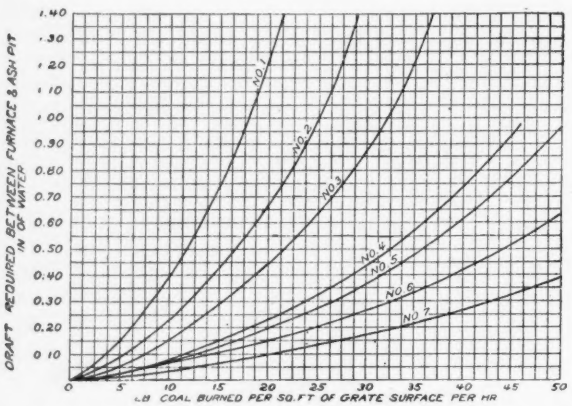


FIG. 2. DRAFT AND COMBUSTION RATES FOR VARIOUS KINDS OF COAL

area of the openings may run as low as 10 per cent of the total area of the grate while with large sizes it often runs as high as 40 to 50 per cent. Table I from Christie gives dimension in general use.

When the weight of coal burned per square foot of grate per hour becomes much below normal, the fire becomes sluggish and hard to manage and economical operation is impossible. If such a condition is to continue over a considerable period of time, it will be found advisable to reduce the grate area sufficiently to bring the rate of coal consumption up to a reasonable rating.

This can be done by blanking off part of the grate area, preferably at the sides, by laying brick upon the grate. If the change is to be permanent, a better way would be to rebuild the side walls of the furnace near the grate and if necessary move the bridge wall forward, thus both narrowing and shortening the grate.

Air Supply

For natural draft it usually is recommended that the ashpit doors be left wide open (they are sometimes entirely omitted) and that the flow of gases through the furnaces be regulated by means of the damper in the flue. The amount of air entering above the grate should be carefully watched. When any considerable quantity of fresh coal is thrown upon the fire, it usually is necessary to keep the fire doors "cracked" for a short time to supply the extra amount of air required. Care should be taken not to "crack" the doors for any longer time than is necessary.

The fire doors are usually provided with draft registers which should be carefully regulated at all times. In the specifications covering the "Chicago Setting" for horizontal multitubular boilers, it is provided that grids be supplied for admitting air above the fire and that the grids should have an area of at least 4 sq. in. for each square foot of grate surface. Sometimes this air is admitted through the bridge wall as described later.

When insufficient air is supplied, smoke results, with accompanying waste of heat. On the other hand, too much air means waste of heat also. If the attendant can see the top of the stack he may be able to judge conditions fairly accurately. The color of the exit gases should be kept neither dark due to the presence of unconsumed carbon nor too far removed from this condition, since there would then be an excess of air. When two or more boilers are served by the same stack, the performance of the individual boilers can be judged less easily. So many conditions enter into the matter of economical firing that hand-firing without the assistance of proper instruments depends to an unusual extent upon the skill and attention of the fireman.

When draft gages and CO_2 recorders are provided and properly used it is possible to operate each boiler more efficiently, but results still depend to a large extent upon the operator.

The theoretical amount of air required is something over 7½ lb. per 10,000 B.t.u. liberated by the coal. Table II is based upon coal of 14,540 B.t.u. heating value, which would require 7.5 × 1.454 or 10.9 lb. of air per pound of coal. Call this 11 lb. of air per pound of coal. There are two reasons for the admission of excess air—inadequate mixing of air and combustible gases and the time required for combustion to take place. The amount of excess air required in boiler furnaces usually runs from 50 to 100 per cent with corresponding percentages of CO_2 from 11 to about 14, as seen in Table II.

TABLE II. RELATION BETWEEN EXCESS AIR, CO_2 AND FURNACE TEMPERATURE

Effect of Percentage of CO_2 Upon Temperature of Fire			
Percent of CO_2 in flue gas	Pounds of air per pound of fuel	Fire temperature deg. F.	Approx. percent excess air
20	12	3310	9
16	15	3190	36
13.4	18	2700	64
11.4	21	2340	91
10	24	2060	118
8.9	27	1850	146
8	30	1680	173
7.3	33	1535	200
6.7	36	1415	227
6.2	39	1315	254
5.8	42	1225	282
5.0	48	1085	336

By far the largest single loss in the steam boiler plant is due to the heat which passes up the chimney. The principal factors contributing to this loss are the

excess air which enters the furnace through the ashpit door or through leaks in the boiler or furnace setting, and the high temperature at which the gases leave the boiler.

Excess air reduces furnace temperature and carries away previous heat units by increasing the weight of gases that leave the boiler at the flue temperature.

Another effect of excess air is to reduce the temperature of the fire, thereby reducing the temperature grading between the gases and the water and correspondingly affecting performance.

It is fortunate that there is a simple and accurate means of measuring this excess air so that it may be regulated. It is based on the fact that the percentage

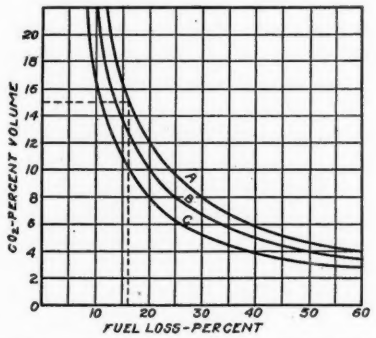


FIG. 3. RELATION BETWEEN CO_2 AND FUEL LOSSES

of carbon dioxide (CO_2) in the flue gases bears a definite relation to the percentage of excess air. Table II shows how the percentage of CO_2 falls as the amount of air per pound of fuel is increased.

Bridge Walls

While the bridge wall is primarily intended to form the rear wall of the grate, it may perform other useful functions. The ordinary arrangement of the setting of the horizontal multitubular boiler in which the gases pass through a relatively contracted passage over the bridge wall and then quickly expand into the combustion chamber serves excellently to assist in mixing the gases at a time when temperatures are high and combustion is progressing. In some forms of furnaces the bridge wall may be so arranged that it serves a useful purpose in maintaining and steadying combustion by its reverberatory action or by the storing of heat.

With certain fuels operating under natural draft, a sufficient amount of air cannot be had through the grate. The admission of extra air through the fire doors has already been mentioned. A more nearly correct place for admitting this air is undoubtedly through the bridge wall. In this case the bridge wall should be hollow, with a space about half as wide as the length of a fire-brick, running through it from one side of the furnace to the other. Fire-bricks should be laid over this space to form the top of the bridge wall, the bricks being set on edge, with their length parallel to the length of the furnace, a clear interval about ¼ in. wide being left between each brick and its neighbors for the exit of the air. Ducts through the brick-work of the setting convey the air to the bridge wall, and dampers are placed in these ducts so that the supply can be regulated at will. Cleaning doors are also provided for removing the fine dust that accumulates in the air passages. Air admitted in this way, as it is more or less preheated in its passage through the ducts in the brickwork, does not chill the boiler and is much more effective in promoting combustion than it would be if admitted through the fire doors.

The bridge wall for a horizontal return tubular boiler is shown in Fig. 4. Note the slanting front which does not crowd the gases against the ring seam and which gives a free entrance into the large combustion chamber.

Hand Firing of Coal

Firing too much coal at one time is bad practice. When it is considered that many coals contain 35 per cent or more of volatile matter which is driven off rapidly after firing, it will be seen that when a large amount of high volatile coal is thrown into the furnace there will be serious losses from the escape of unburned gases.

Whether the spread, coking or alternate method of firing is best can only be determined by trial. If coal cakes over the surface it should be broken up, but care should be taken to disturb the fire only when it is necessary. Clinkering coal causes incomplete combustion by the ash in the coal melting and forming a thin layer on top of the grate bars which prevents the air from passing through.

The inexperienced fireman attempts to relieve this condition by free use of the slice bar, pushing it under the fire over the grate and turning the fire upside down. This mixes the clinker among the burning coals, where

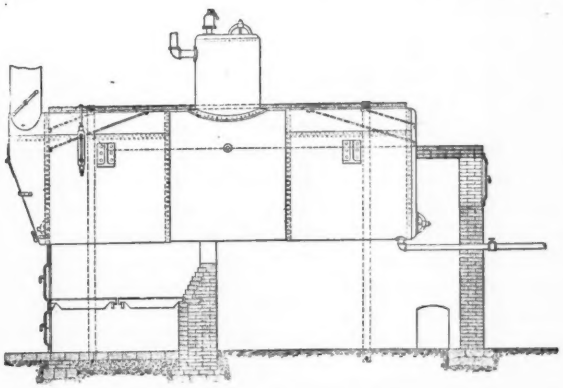


FIG. 4. BRIDGE WALL IN HORIZONTAL TUBULAR SETTING

it again melts and fuses the coal together, making a mass which will not burn at all. In a situation like this, the less disturbance of the fire the better. As soon as the grates begin to cover over, the fire should be burned down as well as possible, and then cleaned. Such clinkering coal can usually be burned successfully on chain grates by running a thin fire and letting the fire alone, cleaning any clinker which does form off the grate as it comes around.

There seems to be no way to determine the proper thickness of fire for a given hand-fired grate or stoker under the draft available other than to run tests with different thicknesses and analyze the waste gases. The

ideal condition is very low oxygen and no CO. This is true for any kind of fuel; as it is usually impracticable to determine hydrogen or hydro-carbons in flue-gas, it is assumed that when there is no CO present combustion is complete.

General practice calls for a thickness of from 8 to 12 in. with soft coals and not more than 8 or 9 in. with hard coal. It often is recommended that the fire be maintained somewhat thicker at the back end than at the front end, which is usually done by slightly inclining the grates and keeping the upper surface of the fuel bed level. The best thickness of fire for any conditions can be determined only by test. To avoid losses due to the distilling off of the volatile portions of soft coal at a greater rate than they can be completely burned, coal should be fed in small quantities. The fire should be kept fairly bright at all times.

When the boiler is in operation, the ashpit doors should not be kept closed for any considerable time because if they are the grate bars are likely to become overheated and either to burn or to warp. On the other hand, have the furnace doors open as short a time as possible when firing coal or working with the fires.

Coal should be burned rapidly and at high temperatures. This can be done best by light, frequent firing. "A draft of 1 in. in the uptake will give good results with 2 to 2¼ lb. of coal per square foot of grate at each firing. This would mean from 6 to 9 shovelfuls on a 6 by 8-ft. grate at intervals of 5 min. With higher drafts intervals would be shorter and with lower drafts intervals would be longer." Good facilities for handling the coal should be provided. Low steel cars or trucks with open side commonly used for this purpose make firing easier and are well worth what they cost.

With poor facilities or management the total losses may run as high as 10 per cent of the coal consumed, while under fair operation the loss will average from 2 to 3 per cent.

Manually operated dampers are usually employed in hand-fired boilers. When these dampers are weighted in such manner as to be closed by the action of the weight they may close suddenly at times, causing blowing out at the fire doors which may result in serious burns to hands and faces of attendants. It is much better practice to arrange the weight so as to open the damper. It is a simple matter to make a rigging to hold the damper closed or in an intermediate position against the effort of the weight to open it. Dampers should always be made so that they do not entirely close the flue.

Hand-firing is not only hard work, but requires considerable judgment and skill if waste of coal is to be avoided. The method of firing to be used in any case depends upon the kind and quality of coal and can best be determined by experimenting with it, and a careful fireman soon learns how to produce the best results.

The fireman should be furnished with proper tools. The shovel should be of proper size and shape for the individual who is to do the work and the end should be kept straight.

The three general systems of firing are known as alternate, spreading and coking. All three are used with bituminous coal. The alternate system consists in spreading fresh coal first on one side of the furnace, then on the other, or through the doors alternately when there are more than two, so that the entire fire is not blanketed with green coal. This system may be used where the grates are wide or when two or more furnaces have a common combustion chamber.

In spreading system, charge a small amount of coal, spreading it in a thin layer over the entire grate at each firing; usually it is spread from the bridge wall toward the door. The use of this system is increasing, since it gives an air supply more nearly proportional to the fuel supply. It means more work for the fireman.

To use the coking system, pile the fresh coal on the dead plate or on the front of the grate, in order that it may become nearly or wholly coked. Then push it back toward the bridge wall and spread it evenly over the grate in order to make room for a new charge. When no dead plate is provided, about one-third of the grate is used to receive fresh coal at each firing. This system is adapted to furnaces in which the gases pass horizontally over the fire.

The spreading and alternate methods give higher efficiency, higher CO_2 and lower temperature of exit gases than the coking system. Steam is generated more uniformly, due to the greater uniformity in furnace temperature. These two methods are widely used in firing non-coking and high volatile bituminous coals.

In the alternate method, although the volatile matter given off by a fresh charge of coal on the one side of the grate is mixed with air which has been heated by passing through the fuel bed on the other side, care must be taken to make provision for the thorough mixing of the gases from the two sides of the fire, and, besides, every effort must be made to keep the two sides of the fire equally thick. Spreading is perhaps more extensively used than the alternate system and has an advantage over the alternate method because the fuel bed can be kept of more uniform thickness, thus minimizing the possibility of holes occurring in the fire.

In the coking method, less of the refuse appears as clinker and more as ash, and more time and labor are required for leveling. The combustible loss through the grate and the amount of slicing and raking are about equal in all three methods.

The coking method is most applicable to those bituminous coals which cake or melt and run together upon heating. With this method, the hydrocarbons must pass over the hottest part of the fire, which is near the bridge wall, on their way to the boiler heating surface. The back part of the fire should be kept thicker, since the coke bed is much more open here than at the front. Two disadvantages of the coking method are that the fire doors must be kept open relatively long in order to work the fire, which results in large quantities of excess air, and that the fire is being continually disturbed, which causes excessive clinkering with coals containing fusible ash.

Anthracite should be fired by the spreading method in small quantities at frequent intervals. The larger sizes of anthracite are now, because of their high cost, but little used under steam boilers. The small sizes pack closely together on the grates and this makes a strong draft necessary. Mechanical draft is usually employed. Owing to the rather high proportion of ash, there is considerable tendency toward the formation of clinker. On this account the use of blowers has been

found desirable and the introduction of steam into the ashpit keeps down the formation of clinkers.

The fuel bed should be disturbed as little as possible. This spreading of the fuel is essential and the fire should be kept at an even thickness. It may be necessary to level the fire occasionally, which can be done with a tee-bar, made from lengths of ¾-in. pipe and an ordinary tee made up to form a head about 12 in. long with a handle of suitable length. Some firemen get good results by leveling the fire with a tee-bar between firings.

The large amount of ash in small sizes of anthracite means a considerable depth of ash just before cleaning, calling for a strong draft. Just after cleaning, the necessary draft is small. This large range in amount of necessary draft calls for blowers maintaining good efficiency over a wide pressure range.

"Free burning" anthracite burns satisfactorily when the foregoing suggestions are followed. In the case of the harder anthracite coals which contain very little volatile matter, it usually is necessary to mix in from 10 to 15 per cent of fine "slack" bituminous coal.

Cleaning Fires

Fires should be cleaned often when the coal contains much ash or when the ash is fusible. On the other hand, light fires can often be run through a 12-hr. shift without cleaning.

Clean thoroughly. Remove all clinker and ash. In spite of the best of cleaning, clinker and ash will sometimes melt and adhere to the brickwork. In removing this, great care should be taken to avoid cracking and loosening the bricks. Cleaning quickly with partly closed dampers will save coal.

In the side method one side of the fire is cleaned at a time. The good coal on the top of the fuel is scraped and pushed to one side, large clinkers are broken up with a slice bar and the refuse drawn out of the furnace. After one side is cleaned, all the burning coal from the other side is moved back and spread evenly over the cleaned part of the grate, after which a few shovelfuls of green coal are added. This adding of fresh coal is necessary in order to have enough live coal to cover all the grate when the cleaning is completed. When the fresh coal is burning well the refuse is removed from the other half of the grate and the burning coal spread over the whole grate.

In the front and rear method the burning coal is pushed back with a hoe against the bridge wall and the exposed clinker removed. The burning coal is then pulled forward and formed into a narrow ridge across the bare grate. The clinker from the back of the fire is "jumped" across the ridge with the hoe, and pulled out through the fire door. The ridge of live coal is then spread evenly over the grate. With this method it is difficult to get a really clean fire without wasting a lot of unburned coal.

An improvement on the front and rear method is to form the front of the bridge wall into a shelf or cleaning table. The live coal is pushed onto the cleaning table, giving every facility for thoroughly cleaning without waste of unburned coal. After the ash and clinker have been removed, the live coal is drawn forward from the cleaning table and spread over the grate. The height of the cleaning table above the grate should be such that it is about level with the top of the layer of ash. This will naturally vary with the quality of coal and with the length of time between cleanings, but about 6 in. will meet general conditions.

Ash Removal

Where ashes are removed by manual labor, the ashpit is usually on a level with the boiler room floor. Greater capacity is sometimes provided by lowering the ashpit floor and a small section of the boiler room floor, thus forming in front of the boiler a pit which is provided with a removable cover. Ashes can be drawn into the pit, thence shoveled into barrow or car by a man standing on the floor of the pit. Another arrangement is to slant the bottom of the ashpit downward from a line flush with the front of the setting back to the front face of the bridge wall. Ashpits often have storage capacity for an 8 to 12-hr. run or longer. Ashes should not be allowed to accumulate in sufficient amount to interfere with the supply of air to the grate.

A small amount of water kept in the ashpit keeps fine particles of ash from being drawn to the fuel bed and has a tendency to soften the clinker.

With chain grate or gravity stokers more or less fine unburnt coal may be dropped through the front part of the grate. This is sometimes caught in a pan but a better method is to provide a hopper whence a conveyor may deliver it to the coal bunker. With this arrangement a rear hopper for clinker and ashes is provided of capacity to hold the accumulation from a full day's run.

With hand-fired grates and gravity underfeed stokers only one hopper is necessary since there is little or no leakage of unburned coal through the grates.

Ash hoppers may deliver directly into an industrial or a steam railroad car. Another arrangement is to convey the ashes by screw or bucket conveyor or both from the hopper to storage bins whence it is loaded into boats, wagons or cars. In a plant recently completed, ashes are collected in the hopper, sprayed from fixed nozzles and discharged at intervals through hand-operated sliding gates directly into steam railroad cars. This method is simple and economical, requiring no power and little attention.

Steam jet ash conveyors which work on the principle of the ejector delivering the ashes from the hopper beneath the furnace to a storage bin are giving good service.

Another method of handling ashes is the vacuum system in which pipes lead from the bottom of the hopper to a closed storage tank in which a vacuum is maintained by means of a positive air pump. In both this and the jet system all entrances to the piping are carefully sealed except those at the boiler through which the ashes are being fed.

Relining

In most power plants the boiler settings receive too little attention. The result is that before those in charge realize that anything is wrong, an arch or a lining is ready to fall down, a side wall is bulged out or a baffle has broken down and the boiler must be cut out of service for repairs. In most plants there are regular intervals at which boilers are out of service for cleaning and internal inspection. If, at such times, a thorough

inspection of walls, linings, arches, bridge walls and baffles is made and all defects repaired, it will save considerable time, annoyance and expense.

In making an inspection of the walls, it should be noted whether or not they show any signs of bulging out at the sides. Especially is this true if the brick work carries either part or all of the weight of the boiler. Where the boilers are supported by an independent iron or steel structure set into the brick work, care should be taken that in the brick work there are no large holes or cracks leading from the furnace to the supporting structure through which the furnace gases may reach the metal, or the steel is sure to be damaged by overheating or corrosion, or both. In one plant, a 500-hp. boiler, the supporting structure was so badly damaged by overheating that the boiler had to be dismantled, the framework straightened up and the boiler reset.

TABLE III. PROPERTIES OF COMMERCIAL FIREBRICK

Characteristics	FIRST GRADE (No.1)			No. 2
	Class A	Class B	Class C	Grade
Safe Fusion Point, deg. F.	3,200-3,300	2,900-3,200	2,900-3,000	2,400-2,700
Compression, lb per sq. in.	6,500-7,500	7,500-11,000	8,500-15,000	14,200-32,000
Relative Hardness	1-2	2-4	4-6	6-10
Size of Nodules	medium	medium to medium large	medium to large	small to very small
Ratio of Nodules	high	medium to high	medium low to medium	low to very low

A thorough inspection of the lining should be made. If any part shows signs of weakness it should be repaired before the boiler is again put into service. Remove all loose bricks and thoroughly clean openings thus formed. Patch with good sound brick, using fire clay mortar and forcing the bricks in tight.

If the boiler is served by a stoker and the setting is provided with inspection doors, the doors should be lined with fire brick or tile to prevent them from being warped out of shape, as it is next to impossible to close a warped door so that air will not enter around it. All inspection doors except, of course, those in the furnace, should have the openings filled with fire brick laid in loosely so that they may be easily removed. They will protect the doors from the intense heat and help to keep air from entering around the door.

After the wall linings and doors have been thoroughly inspected and repaired, the doors should be closed tight and the damper opened wide. Then by going over the setting with a lighted candle or torch, any air leaks may be located. It is a good idea to give the setting a carefully applied coating of good plastic cement at least once a year. This, especially in the case of good substantial brickwork, will insure a setting as near airtight as it is possible to have.

The bridge wall also should be inspected, for clinkers will adhere to it and bricks will be loosened in prying the clinkers off. These bricks should be replaced.

Baffles should be carefully inspected to locate any holes and cracks that will permit the gases to short-circuit the heating surfaces. Baffles seem to be subject to the habit of forming these holes and cracks, and unless they are inspected and repaired at regular intervals may be the cause of a great deal of fuel waste.

Among the worst enemies of boiler settings are steam and water leaks, which allow water to reach the brick work and especially the arches. In most boiler plants may be found any number of leaks around flanges, stuffing boxes and other joints, which allow water to drip or possibly run in a stream down on the setting. Water will soften the brick and mortar and cause them to fall out. If water is permitted to reach the setting, it is sure to cause trouble sooner or later.

Arches should also receive attention. When a sprung arch gets into bad shape there is nothing left to do but to tear it out and rebuild, as it is next to impossible to make any repairs that will be anything like permanent. It is different with the suspended arch. If a tile or brick becomes damaged, it may be removed and another slid into its place. When the brick or tile of a suspended arch becomes damaged to any extent it should be replaced at once, otherwise the intense furnace heat will soon damage the supporting iron work. If the tile is kept in good repair it will last indefinitely; but if not, it may fail at almost any time, due to failure of the iron work. If water reaches the arches they will soon be damaged beyond repair.

A good stout foundation is one of the best preventives against the formation of cracks in the setting, although it has little direct effect upon the action of heat upon the brickwork.

Where relining or repairing is to be done, it becomes necessary to choose the proper brick. Table III gives the properties of commercial fire brick. Figure 5 illustrates some of the many standard shapes.

The fusion point is the temperature at which the brick will fuse or melt. Fire clays become plastic or begin to be soft at a temperature lower than that of fusion. This is commonly called the critical temperature and is the temperature at which the brick will change form under pressure. A brick is of little value in a setting after it has reached a temperature all through its body equal to the critical temperature. A high fusion ordinarily indicates that the critical temperature is high.

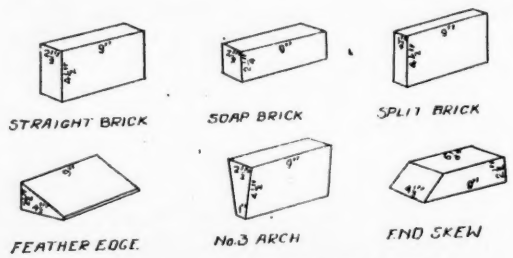


FIG. 5. PROPORTIONS OF COMMERCIAL FIREBRICK

Compression is the number of pounds necessary to crush the brick at the center of the 4¼-in. face by a steel block 1 in. square.

Relative hardness is expressed by a number in an arbitrary scale of 10, and indicates the relative tendency to cracking and spalling. The greater the indicating number the greater the probable amount of cracking and spalling. Spalling takes place on the inner ends of combustion arches which are swept by the gases at high velocity and full furnace temperature.

Cold air, on being admitted to the furnace, chills those parts of the brickwork exposed to it and causes strains which may result in cracks. Care should be taken to avoid confusing compression and hardness.

The higher the fusion point of a brick, the weaker and softer it is (Table III). It is best to choose a brick with a strength just sufficient to meet the requirements and thus obtain high fusion temperature and low hardness.

Firebrick arches and linings should be laid up in properly chosen, carefully mixed mortars. The mortar should be of practically the same composition as the brick itself. Finely ground fire clay mortar should be used for fire clay brick; silica cement for silica brick; and magnesia cement for magnesia brick.

With the grade of brick selected best suited to the service of the boiler to be set, the other factor affecting the life of the setting is the laying. It is probable that more setting difficulties arise from the improper workmanship in the laying up of brick than from poor material, and to insure a setting which will remain tight it is necessary that the masonry work be done most carefully. This is particularly true where the boiler is of such a type as to require combustion arches in the furnace.

Red brick should be laid in a thoroughly mixed mortar composed of one volume of Portland cement, three volumes of unslaked lime and 16 volumes of clear sharp sand. Each brick should be thoroughly embedded and all joints filled. Where red brick and fire brick are both used in the same wall, they should be carried up at the same time and thoroughly bonded to each other.

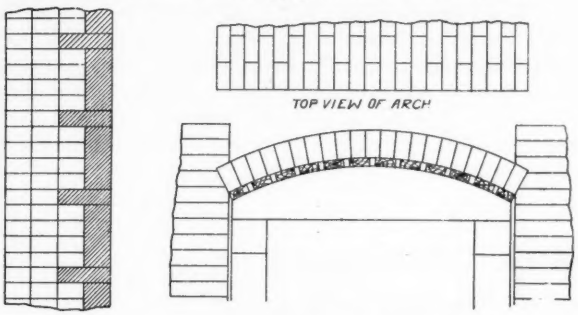


FIG. 6. LINED FURNACE WALL
FIG. 7. CENTERING OF FURNACE ARCH

All firebrick should be dry when used and protected from moisture until used. Each brick should be dipped in a thin fire clay wash, "rubbed and shoved" into place, and tapped with a wooden mallet until it touches the brick next below it. It must be recognized that fire clay is not a cement and that it has little or no holding power. Its action is that of a filler rather than a binder and no fire clay wash should be used which has a consistency sufficient to permit the use of a trowel.

All firebrick linings should be laid up four courses of headers and one stretcher (Fig. 6). Furnace center walls should be entirely of firebrick. If the centers of such walls are built of red brick, they will melt down and cause the failure of the wall as a whole.

Firebrick arches should be constructed of selected brick which are smooth, straight and uniform. The frames on which such arches are built, called arch centers, should be constructed of batten strips not over 2 in. wide (Fig. 7). The brick should be laid on these in courses, not in rings, each joint being broken with a bond equal to the length of half a brick. Each course should be first tried in place dry, and checked with a straightedge to insure a uniform thickness of joint between courses. Each brick should be dipped on one side and two edges only and tapped into place with a mallet. Wedge brick courses should be used only where necessary to keep the bottom faces of the straight brick course in even contact with the centers. When such contact cannot be exactly secured by the use of wedge brick, the straight brick should lean away from the center of the arch rather than toward it.

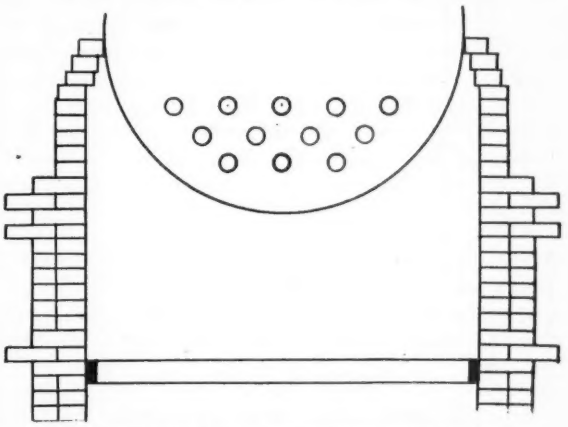


FIG. 8. FIRE WALL OF HORIZONTAL TUBULAR BOILER

Arches should be constructed so that they will meet no interference when expanding and contracting. They should not be tied into any front wall brickwork or carry the weight of any other part of the setting. As far as possible, the arch should be exposed to the same conditions over its entire length above as well as below. For instance, if an arch within a boiler setting is made a continuation of the Dutch oven arch outside the setting, there is liability of the arch failing.

A good arrangement of stretchers and headers for the lining of a horizontal multitubular boiler is shown in Fig. 8. By this construction, the first course immediately above the grate bars is a stretcher, which will not have as much wear as the second course, which, being headers, holds it in position, so it is not likely to be pulled out. Even should it be, it is not a hard matter to insert another one in place of it. The greatest wear is at that point occupied by the seven courses of stretchers, and this construction permits them to be replaced with little danger of having the upper work come down. The headers which back the seventh course tie into the third row and make a firm support that will probably hold, even if the second row should become loose.

Stokers

When once a stoker is installed the method of operation is fixed regardless of the kind of coal used. It is only when a stoker is being used out of its proper field that it gives serious trouble.

Chain grate stokers have two adjustments for accommodating them to the load conditions and the burning qualities of the coal, which are the rate of travel of the grate and the thickness of the fire bed. The coal should

be burned completely before it goes into the ashpit; but the length of dead fire should be small, since excess air with attendant losses will result. Coal which ignites slowly will burn slowly and hence must travel slowly, and will require a thicker fuel bed than would be required under the same load for another coal that burns rapidly.

If the coal does not ignite rapidly or if it goes out after igniting it will be necessary to change the ignition arch or bridge wall so as to bottle up the heat to get higher temperatures, while if to accommodate the load the fuel bed has to be so thin that it burns out too early and admits excess air, the ignition arch or bridge wall will have to be changed so as to give lower temperatures.

Front and double side feed gravity stokers have but one adjustment, the rate at which the coal is fed to the grate. With these stokers holes may develop due to the caking of the coal and the fusing of the ash and it is necessary to break up the cakes with a bar to allow the free flow of the coal.

With underfeed stokers, the attendance consists in keeping the coal supplied in proper amount and in regulating the draft to supply the required air. The work of keeping the fuel bed free from clinkers and of dumping the ashes will depend upon the rate of firing, the percentage of ash and its fusing temperature.

In the case of the sprinkling type of stokers which fire by the spread system, both the frequency and quantity of firing can be adjusted to suit the load and the fuel bed conditions. It may sometimes be necessary to level the fuel bed, but as a rule the first should be disturbed as little as possible since the sprinkling of the fuel forms a porous bed which is ideal for the admission of air through the grate.

When the forced draft fan is driven by steam, it is customary to operate a balanced throttle valve in the blower engine or turbine steam line by means of a standard pressure regulator, by which a drop in steam pressure automatically sends more steam to the fan engine until the additional air from the fan has resulted in raising the steam pressure to normal and, on the other hand, an increase in steam pressure operates to reduce the supply of air.

In small installations, the stokers may be driven from the fan engine, in which case the speed of stoker and fan vary together so that the delivery of both air and coal are controlled from the boiler pressure. In large plants, it usually is advisable to have different driving units on fan and stokers.

Another arrangement is to have the speed of fan engine controlled from the boiler pressure as just stated and the speed of the stoker engine controlled from the blast pressure by means of a pneumatic regulator, thus making the stoker engine lag a little behind the fan engine in its speed changes. In one pneumatic regulator the draft pressure in the main duct acts upon a balanced, oil sealed plunger the motion of which operates a balanced throttle valve on the stoker engine in a manner similar to the action in the steam pressure regulator.

Stoker gears should be protected from dust and should be cleaned and lubricated regularly. Wear can be materially reduced by keeping all accessible bearing and sliding surfaces well greased even where no special provision is made for lubrication. The stoker engine (or turbine or motor) and the drive should be protected from dust as fully as possible and be kept well lubricated.

Most manufacturers have succeeded in making their designs so that links, bars and other rapidly wearing parts, especially those which are close to the fire, are easily replaced, and operators usually make a practice of keeping extra parts.

When overhauling, the stoker should be put in the best condition possible by cleaning and by replacing parts showing unusual wear and which will probably soon have to be renewed. All supports, shafts and other parts should be examined for alinement and straightened up if necessary. All air ducts and windboxes should be examined for tightness.

Maintaining Pump Efficiency

CHARACTERISTICS, INFLUENCE OF OPERATING CONDITIONS, CONSTRUCTION DETAILS AFFECTING EFFICIENCY

IN ORDER that pumps may be kept in good repair, they should be inspected periodically, preferably once a week. Particular attention should be directed to the stroke action, whether it be too long with striking of the heads or too short with diminished capacity and increased steam consumption, and to the amount of leakage and amount of slip. Strokes should be steady and of uniform length. Length of stroke should be as long as practicable without striking heads. When inspecting a duplex pump, compare the action of the two sides for length and time of strokes.

SPEED CONTROL

PRESSURE governors regulate the pump so as to furnish the water at a constant pressure head. They consist of a pressure reducing valve in the steam pipe actuated by slight variations in water pressure. They are particularly useful in places where the water is required at practically constant pressure in varying quantities and especially when the steam pressure is likely to fluctuate. A well known make is shown in Fig. 1.

Float governors are used when it is desired to keep water at a definite level in storage tanks, and the like. In their simplest form, a float resting upon the surface of the water in the tank controls the setting of the steam throttle valve of the pump, closing the throttle as the water level rises and opening it as the water level falls. Usually when a pump is used to raise the water from a well to an open heater the operation of the pump is controlled by the position of a float on the water of the storage space of the heater.

STROKE CONTROL

WHEN adjustments are correct and suction is tight, pump will make strokes of proper length and duration of all strokes will be very nearly equal. Air leakage in the suction will usually be indicated by a quick shooting forward of the piston at the beginning of the stroke

followed by a fairly steady pull to the end. Much leakage will make the pump inoperative. If suction pipe is provided with a foot valve, leakage in it may usually be detected by putting pressure upon the suction line. When doing this, it is best to have the suction pipe filled with water. A short stroke of one piston, in a duplex pump, is often caused by the difference in the tightness of the packing, of both piston and piston rod on the two sides, that side having the tighter setting taking the shorter stroke.

Striking of heads may be due to clogging up of the cushioning ports or to improper setting of the valve stops, which latter may also cause short stroking.

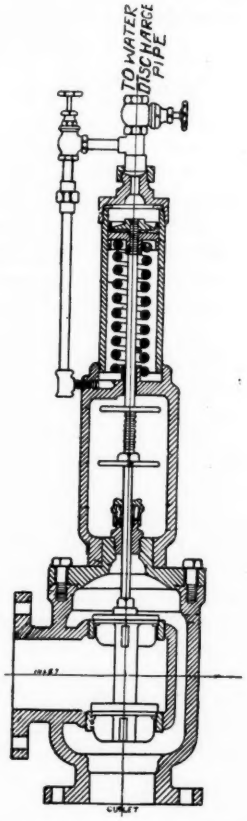


FIG. 1. SECTION OF TYPICAL PUMP GOVERNOR

SUCTION

IN PUMPING hot water the amount of suction head is limited by the lower vapor tension at the higher temperatures. The curves given in Fig. 2 illustrate the manner in which temperature of suction affects the lift. Curve A gives the theoretical lift, B, the maximum lift obtained under favorable conditions, while C shows the actual lift obtained under ordinary conditions.

These curves are based upon 3 to 4 ft. velocity per second and short suction pipe with one bend. It is important to note that all feeds from about 155 deg. F. up must be forced into the cylinder by pressures varying from zero at about 155 deg. F. to about 10 ft. of head at 212 deg. F. It follows that any attempt to raise water without greater suction heads than those indicated will cause vaporization so that the vapor will fill the cylinder of pump and the pump become inoperative.

Make suction pipe as short as possible and avoid all unnecessary bends, leaving no places where air pockets may form. Diameter of the suction pipe should never be made smaller than the suction opening on the pump, and operation may often be greatly improved by making it one or two sizes larger than the suction opening. Velocity in the suction pipe is usually limited to from 2 ft.

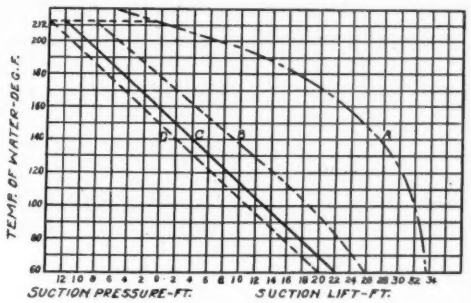


FIG. 2. SUCTION LIFT AS AFFECTED BY TEMPERATURE OF WATER

per sec. for small pumps up to 4 ft. per sec. for large pumps.

A centrifugal pump should be placed at or below the level of the water to be pumped when possible, for a suction head is not taken care of so efficiently as a discharge head. When it is necessary to place the pump above the suction water level provision must be made for priming, since it will not start unless the pump casing and suction pipe are completely full of water. A centrifugal pump will not lift hot water—the water must flow into the pump.

A foot valve should be attached to the suction pipe whenever the lift is high or whenever the pipe is of

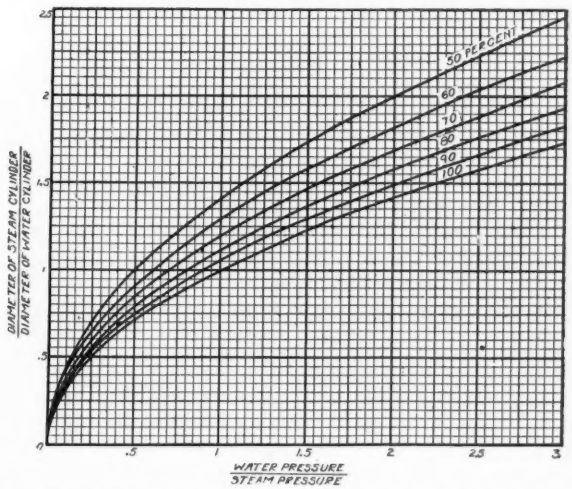


FIG. 3. DIAMETER OF STEAM AND WATER ENDS FOR VARIOUS MECHANICAL EFFICIENCIES

unusual length. The area of the clear water-way through it should be not less than that of the suction pipe.

For priming small pumps, a hand operated air pump may be attached to the suction connection while with large pumps an ejector is a common method. The ejector should be connected to the top of the pump casing and

will raise the water up to the top of the pump provided there is no leaking in of air at the shaft or discharge connection. Priming may also be done through a connection to any source from which water will flow into the suction pipe. If a foot valve is provided priming will only be necessary when first starting up and provision for priming may then be the simplest possible.

Head and Pressure

In figuring pressures and heads the following will be of service:

Pressure of water in pounds per square foot equals head in feet times 62.4.

Pressure of water in pounds per square inches equals head in feet times 0.433.

Vacuum head of water in feet equals inches of vacuum in mercury times 1.13.

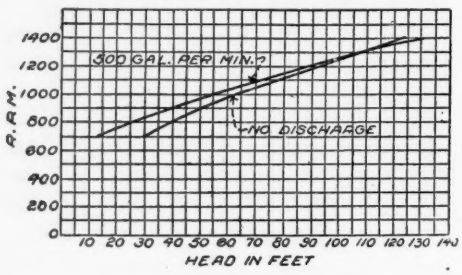


FIG. 4. SPEED-HEAD CURVES

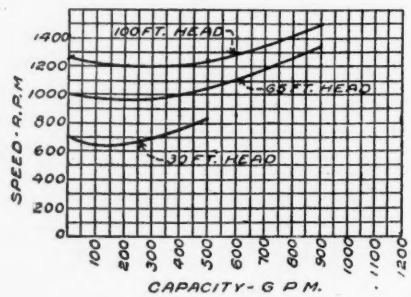


FIG. 5. SPEED-CAPACITY CURVE

Vacuum in pounds per square inch equals inches of vacuum in mercury times 0.489.

Water weighs 62.355 lb. per cu. ft. at 62 deg. F. and 59.76 lb. per cu. ft. at 212 deg. F.

In case it is required to find corresponding pressures and diameters for steam and water ends, Fig. 3, can be used. Suppose we wish to pump water at 200 lb. pressure with steam at 125 lb. pressure at an assumed total efficiency of 80 per cent; dividing 200 by 125, we have 1.6. Find this on the scale marked Water Pressure ÷ Steam Pressure and proceed upward to line marked 80 per cent; from this point proceed to the left-hand scale where 1.41 is found. The diameter of the steam cylinder will have to be made not less than 1.41 times diameter of water cylinder or say, 7 in. for a 5 in. water piston.

Capacity and Speed

In a reciprocating pump the slippage may run from 5 to as high as 20 per cent, but should not be over 10 per cent for a pump in fair condition, and with care may be kept down to 5 per cent.

In a centrifugal pump, there is a direct relation between speed and head, and speed and capacity. These are most clearly understood from an examination of the accompanying curves made from tests on a 4-in. pump. While curves from different pumps vary greatly, these given bring out the general characteristics, Fig. 4 showing the manner in which the head increases with the revolutions per minute, for a constant delivery.

The speed-capacity curve, Fig. 5, shows the relation between these two items where the pump is discharging against a constant head. It is to be noted that there is a minimum speed and definite corresponding capacity for each head. These are about 630 r.p.m. and 140 g.p.m. for 30 ft. head.

Steam Valves

The steam valves of simplex pumps are usually steam actuated. In some cases an auxiliary valve operated from the piston is employed. For this latter case and for duplex pumps, the following rule for setting the valves will ordinarily apply. "Place the pistons in the center position as follows: With piston in striking position at each end, mark on the rod against the gland, then mark the rod halfway between. When this mark is against the gland, the piston is in the center of its stroke. When pistons have been placed in mid-stroke, the valve motion arms should be perpendicular; if not, adjust the crossheads until they are. Then remove the steam chest covers and place the valves in mid-position. As there is no lap, the outer edges of the valve will be in line with the outer edges of the steam ports." In this position, the tappets on the valve stem must be equidistant from their respective striking surfaces on the valve motion.

Valves need as much attention in the matter of leakage as most steam using apparatus. In pumps which exhaust into the feed water system, leakage does not mean so direct a loss. Owing to their position in the steam line the steam is usually very wet at the pump with resulting wear of the valve surfaces. Refacing or renewal of bushings or rings must occasionally be done.

Water Valves

The flat disc is by far the most commonly used water valve in pumps. The disc of the valve is usually made of rubber, a soft quality for vacuum and pressures up to 75 lb., hard rubber for 75 to 150 lb., specially hard vulcanized rubber up to 300 lb., and metal discs for pressures higher than 300 lb. per sq. in. Metal is usually used for hot water for all pressures. It is customary to fit a metal cap over composition valves to keep them from warping and to take the bearing pressure of the spring. Both faces of composition discs may be used. Seats are usually made of bronze or gun metal, forced or screwed into the "deck," so as to be renewed if necessary.

Valves are most commonly set to rise ¼ in. The higher a valve rises from its seat, the longer will be the time required for it to seat, and the greater will be the slip. On the other hand, the higher the lift, the freer the opening. The springs must not be sufficiently heavy to add materially to the resistance of the valve by restricting the flow, yet should serve their purpose

of closing the valve quickly, and thus reducing slip. With the springs, passages and lift as ordinarily arranged, the loss in pressure through disc valves is about ½ lb. or 1.15 ft. of head.

Air Chambers

In addition to the friction due to long suction lines there is, in the case of reciprocating pumps, the complication introduced by the starting and stopping of the long column of water. This can be helped by the use of the suction air chamber, which furnishes an air cushion to take up the momentum at stopping and to assist the flow at starting. When a suction chamber is used, it should be placed in line with the flow of water as shown in Fig. 6, and is ordinarily given a volume twice the displacement of the pump, with proportions high and narrow. Such chambers are more necessary with simplex than with duplex pumps.

In order to give a more uniform pressure in the system furnished by a reciprocating pump, as well as to improve the operation of the pump, an air chamber is always put upon the discharge end. This chamber should be mounted at the highest point of the valve chest, above the delivery opening in order to hold the air and must be provided with some means of renewing the air as this will be rapidly absorbed by the water,

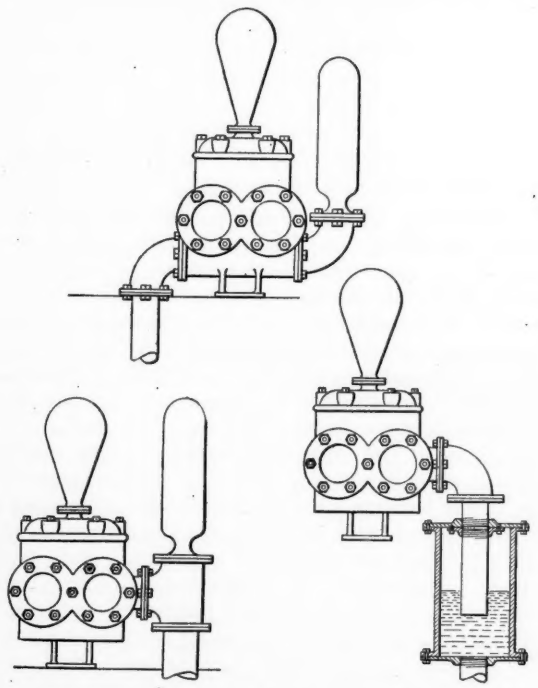


FIG. 6. ARRANGEMENT OF SUCTION AIR CHAMBER TO CUSHION IN DIRECTION OF FLOW

particularly at pressures above 300 lb. per sq. in. For a simplex pump under moderate pressures and speeds the discharge air chamber should have a capacity not less than three times the piston displacement. For a fire pump this should be six times. Duplex pumps, due to the fact that the discharge is more uniform, are well served with discharge air chambers ½ to ⅔ as large as those required by simplex pumps.

The diameter of the neck of the air chamber on either suction or discharge is usually made about ⅓ the diameter of the chamber.

Air pockets in the pump chambers must be avoided, in both suction and discharge ends, as they permit a churning back and forth without flow, due to compression and expansion of the air contained in them, with the motion of the piston. This air binding, as it is called, seriously reduces the capacity of the pump.

Air chambers should preferably be provided with glass gages and with a pet cock on top for letting out

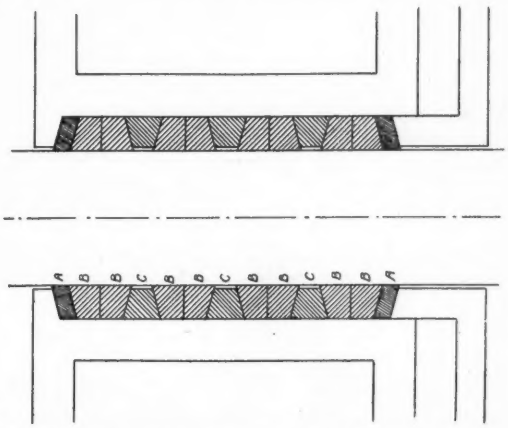


FIG. 7. ARRANGEMENT OF SOFT PACKING FOR HIGH PRESSURES

any excess of air and for keeping the water level at the proper height. In a closed system such as with elevators, since the water does not carry much air it may be necessary to provide on air charging pump or to make connection with an air compressor.

Pistons and Cylinders

Pistons and cylinders on steam ends require about the same attention as other steam cylinders. Metallic packing is the rule, and should have plentiful lubrication.

Water pistons and plungers require constant attention. For cold water and thin liquors four fibrous packing rings ¾ in. square are usually used. Fibrous packing rings should be cut about ⅛ in. short of meeting, in order to give room for expansion. It should fit into the recess with moderate tightness, joints being broken. Coating the packing with cylinder oil and graphite gives good joints, easy action and easy removal. It is a good plan to soak the packing in hot water for a few hours before inserting. Fibrous packing should not be used too long, as pieces of fiber will become loose and cause trouble with the valves. If the pump handles hot water, and if the suction lift is large, packing should be examined at least as often as once a month.

For hot liquids and liquids that must be kept clean, snap rings are ordinarily found to be more satisfactory.

In the plunger and ring type no packing is used, the plunger being made a close fit with a metal ring which is held in the center of the cylinder by stud bolts. About 0.001 in clearance is allowed. The ring is made of bronze so that any scoring will take place on the ring and not on the cast-iron plunger. When worn, it may be replaced at an expenditure less than that required to renew a plunger.

An arrangement of soft packing that has been recommended for high pressures is illustrated in Fig. 7. It is arranged to form sealing spaces similar to those used in some full metallic packings. At A are indicated centering rings which are necessary in case clearance around the plunger is large. These may be made of hard duck if no other suitable material is at hand. Rings C are made of hard duck which need not be more than half the thickness of the soft packing. These should fit the outside of the cavity and stand away from the plunger about ⅛ in. The ends should be lap jointed and fastened so that they will hold together when shoved into place. Rings B are made of jute or hemp (so-called flax) packing preferably boiled in a good mineral oil until they are thoroughly impregnated. Figure 7 shows the hard and soft rings alternated so as to form three "water spaces." If this does not fill the stuffing-box, balance may be filled up with the soft rings. This arrangement calls for a deep stuffing-box which is one

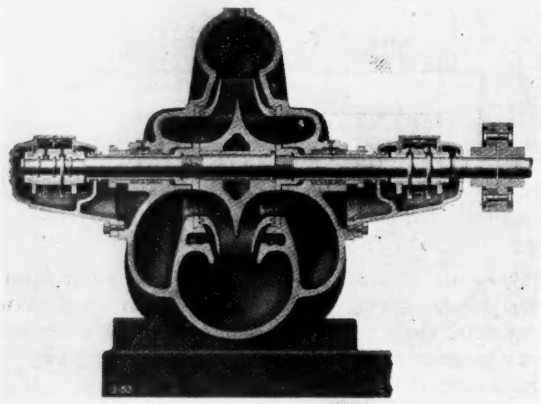


FIG. 8. SECTIONAL VIEW OF TYPICAL CENTRIFUGAL PUMP

item worth considering when buying equipment. Shallow boxes mean frequent tightening with consequent wear on packing and plunger in addition to high friction loss. This arrangement is suitable for pistons. Should lubrication be necessary, let the packing leak a little; clean water is a good lubricant, and a slight leakage indicates that the packing is not set up too tight. Heavy oils and grease should not be used. Pump cylinders are usually made with a lining which is either forced in or is held in place by stud bolts at the end, the latter construction being preferable as it is then easier to replace the liners. Pump ends should have generous clearance.

Impellers

In order to obtain the best results, centrifugal pumps ought to be chosen very carefully, in co-operation with the manufacturer, for the service in which they are to be used. Design depends upon a number of factors of which the more important are capacity required, total lift, variations in suction and discharge lift, horizontal run, liquid clean or gritty, temperature, specific gravity, service continuous, intermittent or at rare intervals such as fire, motive power.

In comparing pumps of different types, the following items should receive especial attention: ease of dismantling, provisions for lubrication, size and construction of bearings, general ruggedness and serviceability. A substantial foundation should be provided, upon which the pump casing must rest evenly, so that it will not be strained when fastened down.

Within reasonable limits for a given service, a pump of small diameter and high rotative speed is more economical in power than one of large diameter and low rotative speed. In boiler feeding and other service handling clean liquid the smaller diameters are employed. In some cases it is necessary to sacrifice efficiency to service.

The amount of water delivered from a centrifugal pump may be controlled within limits either by changing the area of the discharge opening or by changing the speed of the pump. In service such as boiler feeding, it is customary to run the pump at constant speed and let the amount of water delivered depend upon the demand. Pumps can be designed so that when running at constant speed considerable variation in demand results in relatively small variations in pressure and in general the power will diminish somewhat with the demand. If, however, a pump is to run continuously at a reduced output, it is usually advisable to adjust the speed to the new conditions,

Clearance, End Balance

It usually is necessary to pack the shaft of a centrifugal pump either to prevent air from entering on the suction side in case of a suction lift or to prevent the liquid from escaping from either or both sides. This is usually taken care of by some form of ring packing providing suitable water seals.

The leakage or slip which takes place between the impeller and casing back into the suction is either taken care of by the "clearance" between these two parts or by means of labyrinth rings. With either arrangement it is necessary to control the shaft and impeller against axial motion in the bearings. Another consideration which makes this control essential is the hydraulic unbalance which makes it necessary to provide thrust bearings in most cases. This hydraulic unbalance is usually small and under favorable conditions negligible in the case of the double-suction single-stage pump and the thrust bearing, although usually provided, need not be arranged to carry much thrust. Thrust bearings and other features are illustrated in Fig. 8. With single-suction single-stage or single-suction multiple-stage pumps the unbalance becomes important and is offset as nearly as possible by providing a chamber opposite the suction entrance into which pressure is admitted through holes in the impeller. Although helpful, this does not balance under all conditions of operation and through clogging up of the equalizing holes or undue leakage out from the chamber may become virtually inoperative. This condition calls for thrust collars, and even these, in cases of unusual unbalance, may not prevent sufficient end motion to bring the impeller into contact with the casing, with greatly increased friction. Driving motors may be seriously overloaded under such conditions. If the motor heats unduly the unit should be put out of service and the pump thoroughly examined inside for clogging, leakage and interference.

Injectors

PRINCIPLE OF OPERATION, TROUBLES AND THEIR REMEDIES

IN SPITE of its limitations the injector holds a secure position among the various forms of power plant apparatus. Due to its ability to take water from a cold supply, heat it and force it into the boiler when the regular system is out of order it may save its cost in a very few hours service. This is largely because cold feed water may cause serious damage due to unusual temperature conditions, especially in boilers in which feed piping connections are arranged for hot feed water. The saving of fuel obtained by the use of different arrangements of injectors, pumps and heaters is given in the Table I.

In a large service station, injectors are much used at certain periods of the day. At light loads, the injectors require little steam. During periods of light station loads at night, they are often used in preference to the high-pressure feed because the steam pressure is more easily regulated on the boilers that have to be kept under fire ready to pick up the heavy morning load.

NOZZLES

THE THREE nozzles are the vital parts of the injector. The steam enters the steam or expanding nozzle

TABLE I. SAVING OF FUEL BY DIFFERENT ARRANGEMENTS

Boiler Feeder	Temp. Water Supply Deg.F.	Heater With or Without	Temp. Supply to Boiler Deg.F.	Saving of fuel per cent
Direct Acting Pump	60	Without	60	0
Injector	60	"	150	1.8
Injector	60	With	200	6.2
Direct Acting Pump	60	"	200	12.1
Power Pump	60	"	200	13.2 "Steam"

S (Fig. 1), in which it expands to a low pressure with very high velocity. It then enters the mixing nozzle or mixing tube V, creating thereby suction in the gap between the two tubes which draws in the water to be handled from the suction chamber J. The steam is condensed and becomes combined with the water partly in the tube V and partly in the tube C. The water is raised in temperature by the heat of the steam. The velocity is high at the throat of the tube C due to the small diameter, and the pressure is low. From this point, velocity falls off with a corresponding increase in pressure.

In order that complete condensation may take place, it is necessary that the water enter the combining tube at the highest possible velocity. This can be done only by keeping the size of the entrance between the expanding and mixing tubes at a minimum and the pressure in the combining tube as low as possible. This is accomplished by giving the combining tube the shape that the jet would assume during the process of condensing.

The lower the pressure in the mixing tube, the higher will be the velocity of entering water and the greater will be the proportion of water to steam in the mixture. The rate of convergence of the mixing tube should, in order to obtain the maximum efficiency from the injector, conform to the rate of condensation of the steam and be modified in length for every variation in pressure of steam and temperature of feed. This requirement is partially satisfied in some injectors by shifting the combining tube.

The shifting of the combining tube also varies the distance between the combining tube and the steam nozzle. This is necessary when the injector is required to give good efficiency under a considerable variation of steam pressure as shown by the following figures from

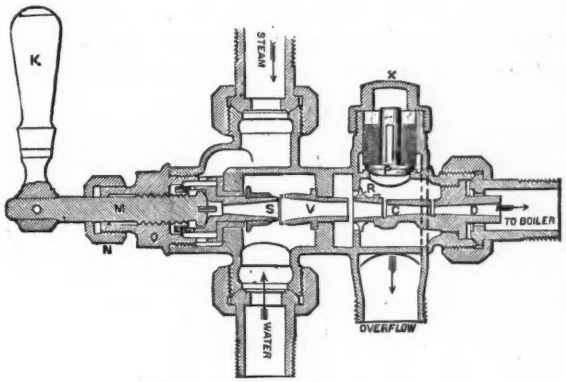


FIG. 1. SECTIONAL VIEW OF INJECTOR

tests on an injector with combining tube adjustable in position:

Steam pressure lb. sq. in.	Distance for maximum capacity in.
120	0.94
90	0.58
60	0.28
30	0.06

Distance as used in this table means distance of combining tube from upper end of its stroke.

TABLE II. TEAM PRESSURES AT LIFTING NOZZLE FOR DIFFERENT HEIGHTS OF LIFT AND TEMPERATURES OF FEED WATER

Lift in ft.	Feed Water Temperatures							
	72 deg.F.		100 deg.F.		120 deg.F.		140 deg.F.	
	Start	Up to	Start	Up to	Start	Up to	Start	Up to
Single Nozzle - Shifting								
Not lifting	20	160	25	125				
2	25	150	26	120				
8	30	130	33	100				
14	42	110	55	80				
20	80	85						
Lifting Nozzle and Forcing Nozzle								
Not lifting	25	360	25	265	35	230	35	140
8	25	300	30	265	35	230		
8	35	270	40	235	45	205	45	110
14	45	240	50	210	55	140		
20	65	185	70	155	65	120	"Relief"	

CAPACITY

IN TABLE II is given steam pressure range at lifting nozzle under different heights of suction and temperature of feed. It is to be noted that the range is given for a "single nozzle-shifting" and for a "lifting nozzle and forcing nozzle." With the non-shifting nozzle, the injector will operate over a pressure range of about 75 lb. Outside of the pressure range, the injector can be oper-

ated at reduced capacity by manipulation of the throttle on the suction line.

Since in the operation of the injector the entering water must condense the steam almost instantly, it follows that there must be a rather definite upper limit to the temperature of the water lifted. Referring to Table II, it may be noted that the single nozzle injector lifts water at 100 deg. temperature for lifts up to 14 ft. while it fails to handle water at 120 deg.

Repairs—Cleaning

The delivery tube is generally the first tube needing renewal—grit or dirt will score it and increase its minimum diameter. Wear takes place most rapidly at a point between the throat and the delivery end where pressure suddenly rises. For a time, this tube can be repaired by smoothing out the roughened places. The injector will operate satisfactorily after minimum diameter becomes somewhat increased.

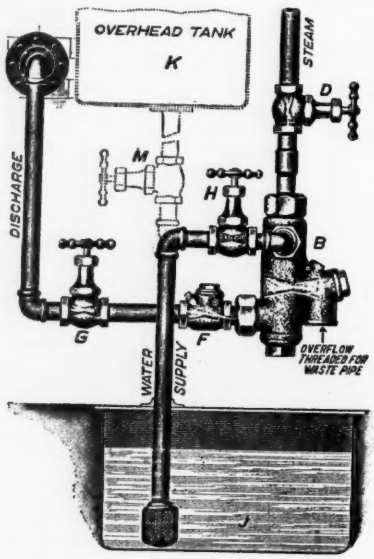


FIG. 2. PIPING CONNECTIONS FOR INJECTOR

To remove scale and deposit from injector parts, disconnect and plug both suction and delivery. Fill injector with a solution made of 1 part of muriatic acid to 10 parts of water. A certain amount of scraping will often be necessary. This should be done carefully so as not to injure the parts. This applies particularly in the case of the nozzles.

Breaking

If the injector "breaks" or fails to lift there are leaks in the suction pipe. If it will not deliver, it may be due to sticking of the check valves in the discharge pipe. To locate leaks in the suction pipe, plug the end, fill with water, close overflow valve, and turn on full steam pressure. Particular care must be given to the packing of the valve in the suction line.

Injector Piping

Connections for an injector are shown in Fig. 2. Steam pipe D should always be the same size at the injector connections, and must be connected to the boiler at the highest possible point, and independently of other pipe in order to insure best results. This pipe should be blown out with steam before connecting the injector.

The water supply pipe should be as large as the injector connections, and where the lift is over 10 ft., it should be one or two sizes larger, reducing to injector size as near the injector as possible. In this line, the Valve H should be a globe valve. On a long lift, a foot valve should be placed on the lower end of the suction pipe. Without a foot valve, every time the injector is started, all air must be exhausted from the suction pipe before water can reach the injector, and considerable steam is wasted. With a foot valve, the water is held in the pipe when the injector is stopped.

When water is delivered from an overhead tank or from city water mains, it frequently happens that a heavy pressure exists, and in this instance, to facilitate starting on low steam, some prefer to use two globe valves, H and M, in the water supply line. Valve H, placed as near the injector as possible, regulates the water supply, while valve M placed several feet away is employed to reduce the pressure. In the discharge line there should be a check valve and a stop valve as shown by F and G.

To start the injector, valve D in the steam line is opened full, then opening valve H in the water supply line, with which the amount of water delivered to the boiler can be regulated. When this valve has once been regulated properly, only the steam valve will be used to start and stop the injector, unless the steam pressure carried has altered to a great extent.

Feed Water Heaters

Types, Temperatures Obtainable, Trouble Encountered

FEED WATER heaters are sometimes mistakenly considered as conservers of heat only. It is well to remember that when the temperature of the water entering the boiler is increased, it is possible for the boiler to deliver more steam and to this extent its capacity is increased. The increase in capacity is in nearly the same proportion as the fuel saving. About one-seventh of the fuel is saved by heating the water from 50 to 210 deg. F. and the steaming capacity is increased by one-sixth. Roughly, 1 per cent of fuel is saved for every 11 deg. of increase in temperature of feed water.

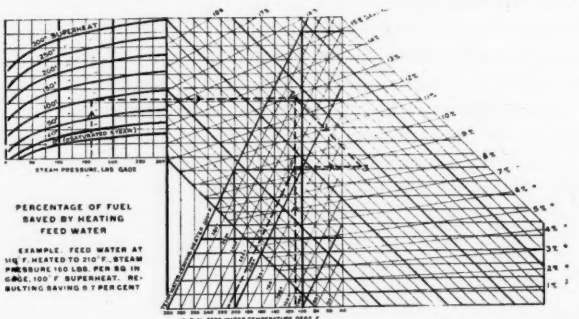

PERCENTAGE OF FUEL SAVED BY HEATING FEED WATER
EXAMPLE. FEED WATER AT 50° F. HEATED TO 210° F., STEAM PRESSURE 150 LBS. PER SQ. IN. GAGE, 100° F. SUPERHEAT. RESULTING SAVING 9.7 PER CENT

FIG. 1. PERCENTAGE OF SAVING BY FEED WATER HEATERS

It may sometimes be advisable to use a closed heater between an injector and the boiler even though the temperature of the feed water may be raised only 50 or 60 deg.

The per cent saving of fuel by heating the feed water may be found from Fig. 1. An example is stated on the figure. By following the dotted lines in the direction of the arrows beginning in one set at the "steam pressure lb. gage" and in the other set at "initial feed water temperature deg. F." we find the per cent of saving at their intersection (Point 3) to be 8.6 per cent. Point 1 is at the intersection of the vertical line of 110 deg. initial feed water temperature and the diagonal line of 210 deg. leaving feed water temperature, and point 2 is at the intersection of the vertical line of 110 deg. initial feed water temperature and the horizontal dotted line from 100 deg. superheat lines.

By delivering hot water to the boiler, less strain is put upon it than would be caused by cold water, and this more favorable condition should be credited to the heater.

Temperature Limit

Due to the intimate contact between the steam and the water in open heaters it is possible when there is plenty of steam to raise the temperature of the water nearly to the temperature of the steam. A temperature of 210 deg. F. is sometimes obtained. With closed heaters, owing to the fact that the heat must be conducted through the walls of the tubes, there must be a temperature gradient of several degrees between the steam and the heated water which may be 15 deg. F. or greater depending upon size of heater and condition of tubes. Coefficients of heat transfer for closed heaters are given in Fig. 2.

Scale and oil do not interfere with heating in open heaters. On the other hand they have the same effect in closed heaters as in boilers by acting as insulators to prevent transfer of heat. The deposit of scale and oil does not, however, introduce as great an element of danger here.

Heaters are sometimes installed so as to be wasteful. The storage capacity of open heaters is often small. The float actuated make-up valve keeps the water level at the highest point, and when a slug of drip water is returned it will overflow to the sewer unless some provision is made to take care of it.

Safety Valves

A relief valve will sometimes stick. For this reason it is advisable to use a relief valve having two or more discs in connection with open heaters as a safety precaution. When exhaust is used for steam heating, relief valve may be adjusted to give higher back pressures when extra heat is needed in the morning to heat up the buildings or for other reasons. The possibility of material increases in pressure should be given consideration when choosing the heater.

Closed heaters as ordinarily installed, carry a pressure somewhat greater than that carried by the boiler. If it is desired to put a stop valve between the heater and the boiler, there should either be a relief valve on the pump discharge, or on the heater, or both. In some exceptional cases, it may suffice to put a stop valve between the pump and the heater and a check valve with no stop valve between the heater and the boiler. In this case, a relief valve would not be required on the heater. The size of relief valve should be chosen to take the full delivery of the feed pump under full boiler steam pressure without submitting the heater to an unsafe pressure.

Blowing Down

All heaters should have provision for drainage and blowing down, and open heaters should be provided with an overflow. In open heaters, it is customary to provide an oil separator as part of the heater, which is ordinarily drained into the waste by means of a trap. Frequency of blowing down depends altogether upon the condition of the water and the resulting accumulating of sediment. Both closed and open heaters should be provided with a scum blowoff.

Scale

In open heaters, the scale which forms on the pans is readily taken care of. Owing to the accessibility, such scale as forms at other places can be removed mechanically with little trouble.

With proper feed water and frequent blowing down at top and bottom, scale should give but little trouble with closed heaters. They are usually built so that by removing one or both heads of the drum access is given to the tubes for mechanical cleaning, as well as inspection and repairs. In some closed heaters, handholes are provided and it is necessary to soften the deposits with chemical solutions and wash it out through these openings. "Boiling out" in a manner similar to that described in the article on boilers may sometimes be done.

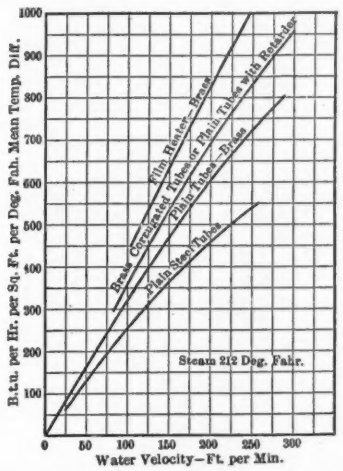


FIG. 2. COEFFICIENTS OF HEAT TRANSFER FOR CLOSED HEATERS (GEBHARDT)

Unless all oil is removed from the exhaust before entering a closed heater, it will soon foul the tubes to such an extent that the feed temperature will be materially lowered.

Leaks

Leaks in open heaters show themselves on the outside of the housing and due to the low pressures carried are usually easily made tight. With closed heaters, leakage from the water side into the steam space can be detected by stopping flow of steam through the heater and putting pressure upon the water. The amount of leakage can usually be measured at the exhaust drain. Small leaks of this character are usually carried away readily by the exhaust drain and cause no particular

trouble. When leakage becomes bad it must be stopped. Re-rolling and calking are usually effective. In choosing a closed heater, it is important to give careful consideration to the provisions for expansion.

Open heaters should be provided with a gage glass. Floats for maintaining the level of the water at a fixed height are essential and these should be kept in good running order. Provision should be made for filling and emptying the storage space by means of hand operated valves.

Overhauling

Heaters, like all other apparatus in a boiler plant, should be overhauled periodically. Particular attention should be given to the presence of oil and scale, to the tightness of joints and strength of parts. Owing to the low pressures carried in open heaters it is usually not necessary to make any particular tests for strength. In the case of closed heaters, an hydraulic test for strength is probably the most serviceable, with such careful inspection of riveted joints and tubes as would ordinarily be given to a condenser or a boiler. In order that the streams of water in an open heater may be properly broken up, it is necessary that the pans be set as nearly perfectly level as possible. In connection with the periodical overhaul, the heater should be carefully leveled so that the flow of water may be as just described.

Economizers

Correct Temperatures, Methods of Cleaning, Inspection

ECONOMIZERS have their greatest value in plants in which the boilers are forced and mechanical draft is employed. On the other hand, they may result in an actual loss in overall economy when installed in connection with feeble chimney draft and underloaded boilers. Plants in which all or virtually all auxiliaries are electrically operated, hence have little exhaust steam, are improved in economy to a greater extent by the introduction of economizers than are plants in which a good supply of exhaust steam is available.

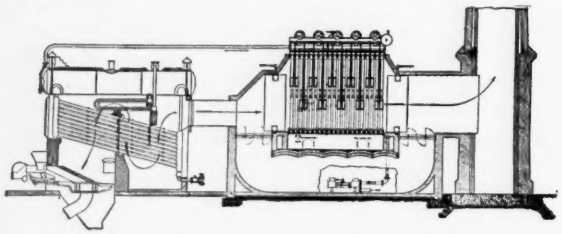


FIG. 1. TYPICAL ARRANGEMENT OF ECONOMIZER

The using of high steam pressures with the consequent higher temperature of flue gases is giving a greater field for the intelligent introduction of economizers; on the other hand, it should be noted that even under these higher steam pressures the advisability of installing an economizer may properly be questioned. As an example, with oil fuel a boiler efficiency of 80 per cent or over is frequently realized and such an efficiency would leave small opportunity for commercial gain through the addition of an economizer.

The addition of an economizer to an existing installation is a matter requiring much close analysis before undertaking.

Typical arrangements of economizers in relation to boiler are shown in Figs. 1 and 2.

Inlet Temperatures

When the temperature of the economizer surface is too low, there is condensation of the moisture in the flue gases upon this surface which, in connection with

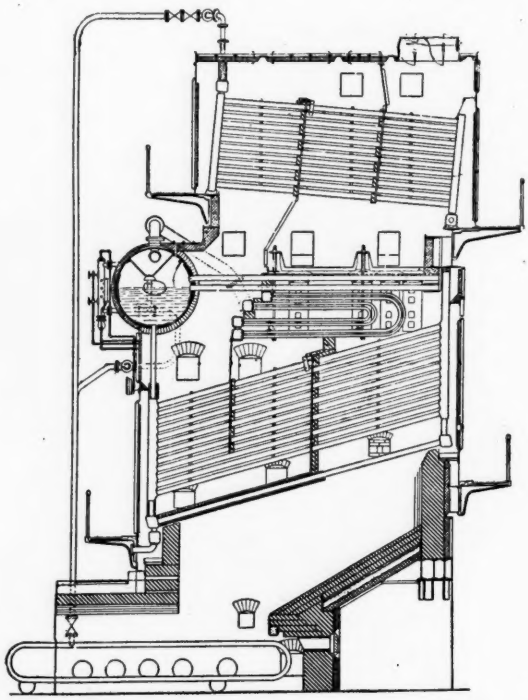


FIG. 2. TYPICAL ARRANGEMENT SHOWING ECONOMIZER PLACED ABOVE BOILER

the soot present, attacks the metal. The agents in this action are the products of the sulphur in the coal assisted to some extent by other elements. This limit not only reduces the effectiveness of the economizer, but makes necessary, in most cases, the employment of additional apparatus to deliver the feed water to the economizer at the higher temperature.

From an English source comes the suggestion that a small portion of the water leaving the economizer be bypassed into the cold feed supply.

The lower limit of temperature of the entering water in an economizer seems to be rather definitely placed for any given economizer and conditions of operation.

While it would be highly advisable from the point of view of efficiency to take the condensate directly from the turbine or engine at a temperature of 80 or 90 deg. F., pump it through the economizers, and thus obtain high differences of temperature and consequent high transfer of heat between the flue gases and the incoming water, the corrosion of the economizers themselves at the low temperatures thus induced prohibits this method, and it has been found instead that it is necessary to heat the water before entering the economizer to about 140 deg. F. in order to prevent the forma-

tion of wet, sooty deposit on the tubes and headers which soon corrodes them to the point of failure. This statement applies to cast-iron and semi-steel economizers, but where steel economizers are used, it has been found advisable in many instances to raise the temperature of the water still higher, to 175 deg. or even higher, and this reduces the overall efficiency of this equipment just that much more.

The following quotation refers primarily to central stations:

"It is believed that most of the corrosion inside of steel economizer tubes is due to gases carried in the feed water, and the chief preventive methods adopted have as their basis the removal of air, oxygen and carbon dioxide. A common method for reducing corrosion in wrought steel economizer tubes is to carry the incoming water at a temperature of from 190 deg. to 210 deg. F.; this may or may not be at a loss of plant economy, depending upon design and conditions of operation, but a plant may usually be so designed as to put feed water into the economizer at a temperature not far from 200 deg., without appreciable loss of overall efficiency. Another method, and one for which commercially developed equipment is available, is to boil the water at some pressure less than atmospheric and thereafter prevent its contact with air."

Exit Temperature

Practically the only high limit to the outlet temperature of the water is the saturation temperature corresponding to the pressure in the economizer. Should this temperature be reached, steam would be formed in the economizer with accompanying annoyance and possible danger. Since the pressure on the economizer as ordinarily installed is as high as and usually higher than the pressure carried in the boiler and since the temperature in the economizer is always, under operating conditions, much below the temperature inside that part of the boiler at which steam is being formed, there is little likelihood of steam being generated in the economizer.

It is hardly necessary to mention that the exit temperature of the water cannot be more than the entering temperature of the flue gases in the case of counter flow and not more than the exit temperature of the gases in the case of parallel flow. The amount of difference in temperature must be sufficient to insure a reasonable flow of heat from the gases to the water at every part of the heating surface—otherwise all or part of this surface will be ineffective and the required area would necessarily be large.

If the exit temperature of the gases is reduced below about 240 deg. F. dew will be deposited upon the heating surfaces. This, it should be observed, is due to the temperature of the gases and not to the temperature of the surfaces, although both conditions may exist simultaneously and both have the same injurious effect.

Although more difficulty from exterior corrosion is experienced with steel tubes than with cast iron, steel economizers are being installed to an increasing extent, especially in large plants.

It is advisable to attach thermometers of good grade on the inlet and outlet water connections.

Soot Blowing and Blowing Down

Soot blowing is now being done extensively on the exterior surfaces of economizers, sometimes in addition to, and sometimes without scrapers. Washing the outside of the piping and headers is sometimes done. After washing it is always best to allow time for the surfaces to become thoroughly dry before putting the economizer back into service. A prominent manufacturer of economizers states that superheated steam for blowing gives better results than saturated steam.

Since no evaporation takes place in the economizer, there is no concentration of the foreign matter and as a result the rate of formation of scale is much less rapid than in the boiler. Scale does form, however. Most economizers are provided with caps located opposite the ends of the tubes which permit cleaning with reamers and other apparatus. Blowing down is necessary also. A great deal of the matter in suspension which would otherwise settle toward the bottom of the boilers settles in the economizers. This can be largely removed by blowing down.

Several large plants make a practice of blowing down economizers once or twice each week to remove loose scale and sludge; also of boring out the tubes once a year or oftener.

Draft Resistance

"We advocate both high water and gas velocity." This is the expression of a prominent manufacturer of economizers and is indicative of the general trend in economizer practice. While high velocity of the water is easily taken care of in the feed system, the management of the flue gases is not so simple. When natural draft is to be used, the resistance of the economizer flues becomes an important factor. This may virtually prohibit the installation of an economizer in an existing installation and in a new plant may make necessary extra expenditure for a stack to give the required draft which may sufficiently offset any gain due to the installation of the economizer. Gas velocities often run about 1000 ft. per min. while the velocity of the water through the heating pipes is sometimes as low as 1 per cent of the velocity in the feed pipes.

It is to be borne in mind that two factors enter here to reduce the effectiveness of the stack. One is the additional resistance to the flow of the gases due to the flue resistance of the economizer. The other is the lower temperature at which the gases enter the stack, which results in a lower draft. The former of these may be kept down by using large flue areas in the economizer and thus reducing the resistance to flow.

When fans are used, the case is different. Either forced or induced draft may be used, with induced draft in somewhat greater favor at the present time. With induced draft fan capacity must be provided for infiltration of air into the economizer of anywhere from 10 to 50 per cent. It should be kept down as much as possible.

The inclosing of one or both sides of the economizer with sectional covers consisting of two steel plates with about two inches of insulating material between them is now advocated, as it permits easy access for purposes of inspection and cleaning and can be kept tighter against infiltration of air than brickwork. It is becoming the practice in many plants to install an econo-

mizer on each boiler without a bypass for the gases. Such economizers become practically a part of the boiler.

Safety Valves

It is customary to provide an economizer with a safety valve which should be of sufficient capacity to discharge easily at the rate that water is fed to the economizer. It should be placed in a convenient position for inspection and should be so arranged that leakage and blowoff from it will not get upon the heating surfaces of the economizer. The safety valve is usually set to blow off at a pressure higher than that at which the safety valve on the boiler is set, the amount of difference being somewhat greater than the difference between operating pressures of the boiler and the economizer.

There are two conditions under which an economizer may be submitted to dangerously high pressure; one is by closing the valves and trapping the water in the economizer without bypassing the hot gases, and the other is by closing the water outlet valve and, with relief valves absent or failing to work, raising the water pressure unduly by means of the pump. Careful and frequent inspection of the safety valve on the economizer is imperative.

Inasmuch as gas explosions sometimes occur within economizer settings, it is desirable to provide quick opening explosion doors therein.

Inspection and Overhauling

Systematic inspections, once a month or oftener, should be made and reported in writing and should include definite statements upon such items as safety valve, tube cleaners including complete driving mechanism, gas passages from boiler to main flue or to stack, dampers, draft resistance and temperature rise. Such repairs and renewals as are found necessary should be made promptly.

It is a good plan to take draft and temperature readings of gases and temperature readings of water at both entrance and exit before and after cleaning. Treatment of scale, soot and ash, and corrosion are much the same as for boilers. With some coals, especially those high in sulphur, rapid corrosion of the soot hoppers, valves and ducts has occurred. Various protective linings, among them concrete, have been tried with reasonable success.

Once a year, at least, the economizer should be given a thorough overhauling. Every bit of metal and brick should be examined for present condition and probable duration of service and be put at once in as good condition as possible.

Superheaters

Desirable Temperatures; Precautions in Operation

THE MAXIMUM temperature for superheated steam is fixed rather by the machine using the steam than by the superheater itself. For Corliss and slide valve engines the temperature ought not to be greater than 475 to 500 deg. F., which means a superheat of 110 to 135 deg. when pressure employed is 150 lb. per sq. in. Higher temperatures cause trouble with the valves on account of warping and poor lubrication. With poppet-valve engines and other engines having valves specially designed for superheated steam, temperatures as high as 600 deg. F. are used. Steam turbines can be successfully operated at temperatures as high as 800 deg., but on account of troubles and expense in maintenance, the present limit is about 650 deg. F. As far as the superheater itself is concerned, temperatures up to 800 to 1000 deg. F. might be employed.

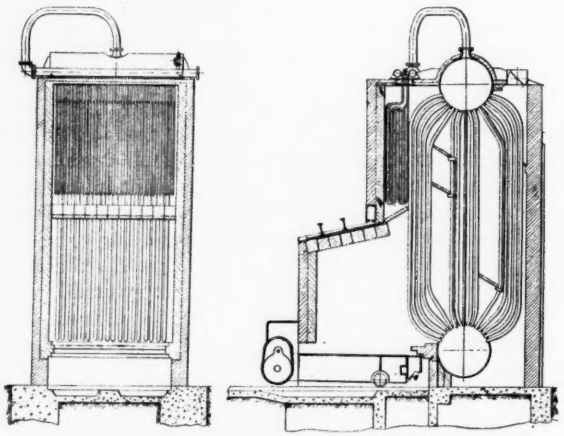


FIG. 1. SUPERHEATER ON VERTICAL WATER TUBE BOILER

Superheaters are designed for high steam velocities, running in some instances as high as 12,000 ft. per min.

When operating under medium or higher ratings under ordinary running conditions, the steam carries away the heat given to it by the gases at a sufficiently rapid rate to prevent the superheater tubes from becoming overheated; but if the flow of steam is greatly reduced for any reason the temperature of the steam and consequently the tubes will rise. Some superheaters are constructed of cast iron and some are protected with cast iron so that they can withstand any temperatures likely to occur. In some superheaters the tubes

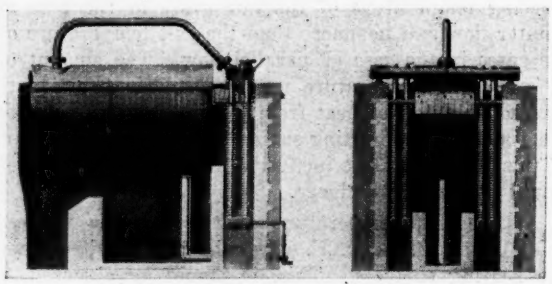


FIG. 2. SUPERHEATER ON HORIZONTAL TUBULAR BOILER

are protected in the event of stopping of the flow of steam by bypassing the gases (this is one of the advantages possessed by the separately fired and the "bypass" superheaters).

Practice varies greatly in the matter of the location of the superheater. In the case of horizontal tubular boilers, it is commonly located at the rear of the setting with tubes standing vertically so as to be in the path

of the gases as they pass from the end of the combustion space into the tubes. In the case of water-tube boilers they may be placed almost anywhere, depending upon the arrangement of the tubes, grate and baffles.

The separately fired superheater is being given a great deal of attention, its advocates claiming the advantage of close control of temperature of exit steam. This is an important point in view of the effect of variations of temperature on the performance of engines and turbines.

The superheaters themselves, especially those integral with the boilers, require little, if any, attention.

In putting a new boiler with a superheater in service, or after it has been shut down for cleaning or repairs, it is advisable, if possible, to fire rather slowly, with the admission of plenty of air, in order that the flue gases reaching the superheater should not be of too high temperature, inasmuch as no steam is flowing through the elements.

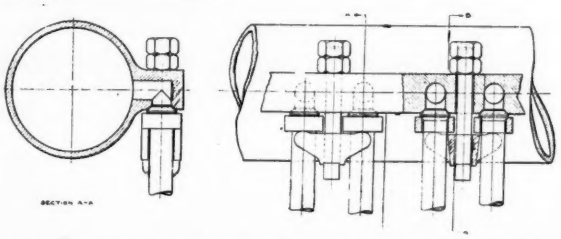


FIG. 3. ONE TYPE OF CONNECTION OF TUBE TO HEADER

Some years ago it was customary to flood superheaters with water when firing up boilers. This has, however, now been entirely discontinued, as practice and experience have shown that there is no necessity of protecting the superheater during the firing-up period. Flooding is more a disadvantage than an advantage because when water left in the superheater is evaporated in the superheater elements, scale deposits on the inside of the tubes, and not only decreases the efficiency of the superheater but also with an increased amount of scale accumulated, the danger of overheating the tubes is increased. While the boiler is being fired up the drain valve on the superheater header should be kept open, so that in case there is any water in the elements or in the header it may be drained off and not carried over to the main steam line.

When the boiler is in operation no special attention need be paid to the superheater other than blowing soot off the tubes at certain intervals. How often the superheater tubes should be blown off depends entirely upon the fuel burned, the draft, and mainly upon the type of superheater. Superheater elements with smooth external surface, located horizontally, should be blown off every time the boiler tubes are blown. On bare tubes located vertically little soot accumulates; therefore frequent blowing is unnecessary. If the elements, however, consist of steel tubes covered with cast-iron rings or gills, a considerable amount of soot accumulates on them, and if not blown off often the space between the cast-iron gills becomes filled up with soot, and the capacity and efficiency of the superheater is noticeably reduced. These elements should be frequently and thoroughly blown off, either with mechanical soot blowers, when such are installed, or by hand with a lance. They should be blown off at least twice as often as the boiler tubes. It is also recommended to clean the cast-iron ribs or gills with a steel brush each time the boiler is down for washing out.

The operating engineer should see to it that the safety valves are set slightly lower, say 2 lb., than the boiler valve. This is essential to provide a flow of steam through the superheater and prevent any overheating of the superheater elements in case more steam is generated than taken away from the boiler, or should the load suddenly be thrown off the boiler or the plant.

Superheaters which are placed in the boiler setting are forced when the boilers are forced; at the same time the temperature of the steam may fluctuate as a result of temporary conditions of firing, such as leaving doors open too long, or firing too heavily or irregularly. But when there are a number of boilers in a battery the temperature of the steam at the engines or turbines should remain fairly uniform, as this would reflect the average conditions.

Inspection of the superheater should be fully as frequent and rigid as that given the boiler, and repairs should be made immediately if any weakness or imperfection is discovered. Since there is no part of the steam-forming equipment that requires closer attention, it is important that the superheater be easily accessible for inspection, cleaning and repairs.

Piping

POINTS TO BE CONSIDERED DURING INSTALLATION; DRAINING; INSULATION; CORROSION

PIPING is used to conduct a fluid from one point to another. It should be planned to do this both economically and safely, the more important of these two being safety. More accidents occur as a result of defects in piping than from imperfections in boilers. While this discussion applies more particularly to piping for steam, nevertheless a great part of it applies to piping for other fluids.

ARRANGEMENT

PIPING should be arranged with runs having as few turns as possible. When it is considered that an ordinary short radius elbow offers as much resistance as a length of pipe about 40 diameters long, it is evident that the presence of many fittings in a line adds materially to the resistance to flow. Pipe bends and long radius fittings should be used whenever conditions warrant.

The best size of pipe is often difficult to choose; while pipe of large size reduces friction, when it is larger than necessary disadvantages result. In general, it should be said that the minimum size which can be counted upon to do the work in an economical manner is the best. The smaller the pipe, the greater the velocity, and frictional resistance to flow increases rapidly with increase of velocity. On the other hand,

in the case of steam, where it is desired to maintain high temperature, a part of this friction work is not lost but operates to keep up the temperature of the steam. Small diameters mean small radiating surface, smaller fittings and less initial expense throughout.

In the past, velocities of steam supply for pumps and engines have been up to 6000 ft. per min. and up to 8000 ft. per min. for turbines. Present practice employs up to 12,000 ft. per min. for turbines and engines, with velocities as high as 20,000 ft. for turbines

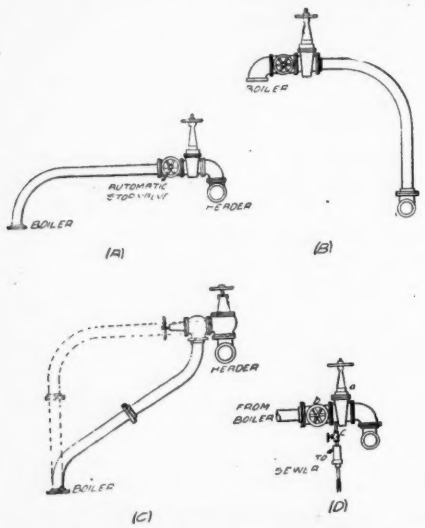


FIG. 1. TYPICAL BOILER BRANCH CONNECTIONS AND PROPER LOCATION OF VALVES

in exceptional cases. Velocities in exhaust piping are kept as low as practicable, about 4000 ft. per min. being commonly employed.

For pressures up to 125 lb. per sq. in., standard fittings are applicable; above 125 lb., extra heavy fittings must be employed.

All boilers must be provided with a stop valve of the gate or globe type, and except in single unit installations the use of some form of automatic non-return valve placed between the main and the boiler is recommended. This should be located at the highest point of the lead and as near the header as possible. Placing the two valves as shown at D, Fig. 1, the automatic valve can be taken apart while the header is in operation.

Two arrangements of branches from header to engine are shown in Fig. 2. A common arrangement with steam separator at the engine is shown at A which calls for drains at two points. At B the drainage feature is much simplified by hanging the receiver upon the header.

Expansion

Provision should be made for expansion. This may be said to be true of all piping whether it is to conduct steam at high temperatures or ordinary service water.

Formerly it was customary to arrange piping with offsets. Such offsets are still used to some extent for piping 6 in. diameter and smaller.

Corrugated expansion joints of various forms have been much used, especially in marine practice, but for stationary work they are not now much employed. This is largely due to the increasing temperatures corresponding to high steam pressures and superheats now coming into vogue. While copper is satisfactory for exhaust lines at relatively low temperatures, it is found to be somewhat unreliable at the high temperatures now in use. The slip joint or packed expansion joint is much used in important work. These joints are usually purchased as a unit and installed between flanged connections; they should always be provided with proper bolts to keep the joint from blowing apart under steam pressure in case the pipe at either side of the joint is loosened from its anchorage. Packed joints are sometimes used as swing joints.

Another method is by means of bends, expansion being taken up by the spring of the pipe in the bends. These bends take up a good deal of room, especially when made of pipe of large diameter. The expansion which can be taken up depends on the length of the pipe in the bend and not on the shape.

Supports

Correct support of piping, especially steam piping of large size, is very important since it affects durability, service, maintenance, and is largely responsible for good appearance.

Piping should be anchored at one or more points to substantial supports. Specially constructed pillars or pedestals located at convenient points to which the pipes are securely attached are often provided, especially in the case of large piping. Care must be taken not only to support the pipe but to anchor it so that it cannot move longitudinally in the saddle or other bracket. If this is not done and the pipe, due to vibration or other cause, works in one direction or the other, undue stress will be put upon some relatively small connection from which failure may result. In case a pipe is anchored at more than one point so as to prevent slipping, proper provision for expansion must be made between these two supports. Where two or more pillars are provided along a run of pipe not having provision for expansion, the pipe may be anchored against longitudinal motion to one of these supports and rollers allowing free expansion provided at the other supports.

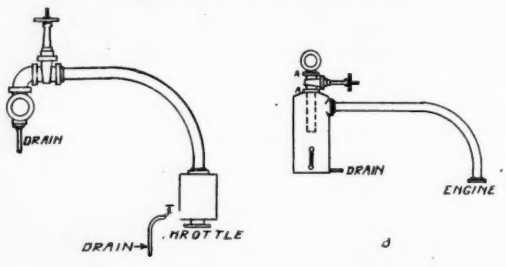


FIG. 2. TYPICAL ARRANGEMENT OF CONNECTION FROM HEADER TO ENGINE OR TURBINE

It is usually more convenient to support the piping upon brackets attached to the wall, and what has been said in regard to pillar supports applies here. When the pipe is located a short distance below the ceiling, hangers are commonly used. Types of anchoring are shown in Fig. 3.

Drainage

Steam piping should be so supported as to avoid water pockets due to sags. With the amount of inclination ordinarily provided for drainage, these pockets may exist without the knowledge of those in charge. They can often be removed, especially in the case of small piping, by raising or lowering the pipe at various points by adjustment of the hangers by shimming the saddles or by other means. If supports are too far apart other supports should be added. Sometimes water pockets cannot be avoided where pipes have to run under or over obstructions. All such points should be properly drained.

The following refers primarily to drips in main steam lines but is applicable with little modification to all high-pressure steam lines. Put drips at the following places:

Lowest point of every fitting in horizontal runs; both sides of every valve in horizontal runs; above all stop valves in vertical lines; at the base of all risers; at all places where water can accumulate because of the closing of a stop valve; at all dead ends and all pockets; at intervals of from 75 to 100 ft. in long horizontal runs.

It should be noted that Table I provides for drips up to 200-ft. intervals for pipe diameters up to 6 in.

The size of drips depends largely upon the conditions. In main lines, ¾ to 1-in. drips are commonly used. When pipes are long and large, sizes of drips may be made 1¼ to 1½ in. Drips from throttle valves and steam chests are commonly made ½ in. irrespective of the size of the unit.

TABLE I. SIZE OF DRIP PIPES IN INCHES

Size of Steam Pipe, in.	Length of Steam Main, ft.	
	0–100	100–200
2	½	½
3	½	¾
4	¾	¾
5	¾	1
6	1	1¼

Water hammer can usually be prevented by proper drainage. Where danger of serious water hammer exists it is customary to provide pockets or receivers of considerable capacity in which the water will be caught before it can reach places in which damage can be done.

Water from all drips should be saved. Condensate from main steam piping and all other piping 4 or more feet above the level of the water in the boiler is usually run directly back into the boiler, the connection for this sometimes being made through the blowoff piping. Suitable valves must be provided to cut off this return

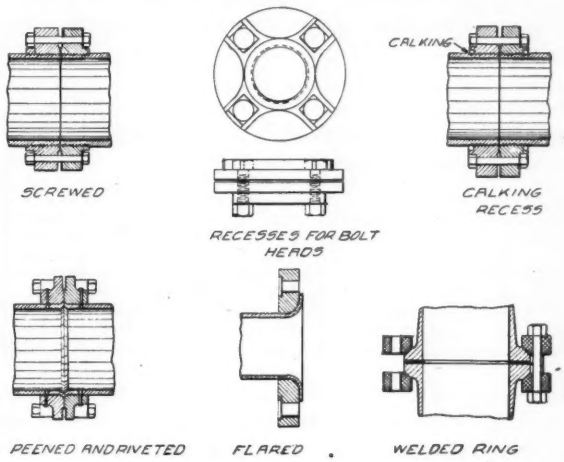


FIG. 4. FLANGE JOINTS

when the boiler is shut down. Often a drain header is run parallel to the main header.

When piping to be drained is not at a sufficiently high level, the condensate may be brought to the hotwell by means of individual pipes if they are short or through a drip main in the case of longer runs. Steam traps are sometimes used, either to send the condensate forward to the hot well in the case of long runs or when actual lifting is necessary in many cases to force the condensate up into a direct return trap for return to the boiler. When returning drip water to the boiler, care should be taken that it contains no oil.

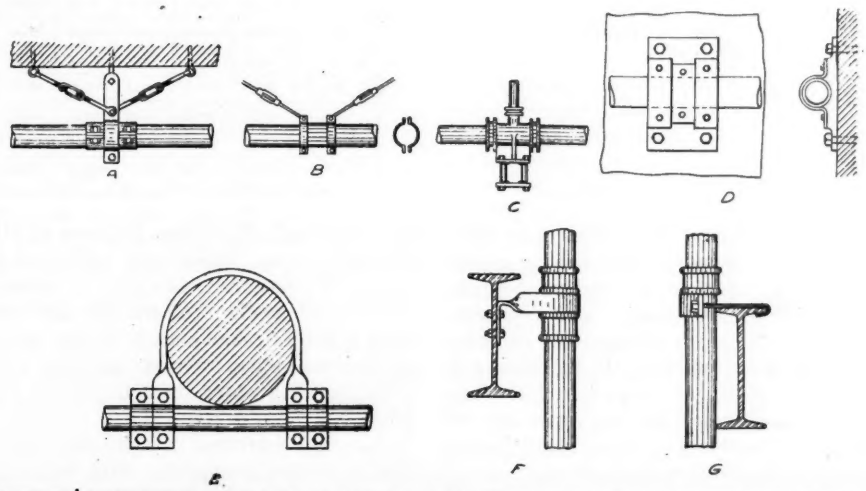


FIG. 3. TYPES OF ANCHORING FOR PIPES: A AND B SUSPENSION ANCHORS; C, ANCHOR TEE; D, WALL SUPPORT AND ANCHOR; E, ANCHOR TO COLUMN; F AND G, ANCHOR FOR RISERS

Valves should be placed on all drips close to drain pipe. These valves should, if possible, be of the same type throughout the plant and it should be easily possible to determine by inspection whether they are open or closed.

Joints

Pipe joints are made either screwed, flanged, or welded. A welded joint is employed in some special boilers on pipes of small size. It has also been used successfully on main headers and other important piping in large plants, although its use is not general. In ordinary practice, screwed fittings are limited to sizes under 4-in., although some authorities recommend that the limit be set at 2½-in.

Flanged connections are made in a number of different styles, several of which are illustrated in Fig. 4.

All piping should be located and arranged for easy accessibility, especially in the case of the joints, which should be placed so that a wrench can easily be used on all flange bolts.

TABLE II. RADIATION FROM STEAM PIPING COVERED AND UNCOVERED FOR 1 FT. LENGTH OF PIPE DUE TO 1 DEG. DIFFERENCE IN TEMPERATURE (MAGNESIA, CANVAS COVERED)

Size of Pipe Inches	Thickness of Covering, Inches					Bare Pipe
	1/2	3/4	1	1-1/4	1-1/2	
2	.472	.374	.314	.272	.250	1.89
4	.787	.615	.510	.443	.392	3.46
6	1.12	.857	.705	.573	.532	4.95
8	1.40	1.07	.874	.744	.655	6.31
10	1.74	1.32	1.07	.908	.792	7.79

Leaks

The loss due to steam leaks is much greater than usually believed. As an indication of how a leak of small area may run into large quantities, the following approximate figures are significant:

Diam. of hole, Inches	Loss, pounds per 24 hr., gage pressure 100 lb. per sq. in.
1/32	70
1/16	280
⅛	1100
¼	4400
⅜	10,000
½	18,000

Leaks around valve stems, due to insufficient or worn packing, bent or bruised valve stems and similar causes are unsightly and can usually be easily stopped. Gaskets are often too thick, and flange bolts are sometimes tightened unevenly; in rare cases one or more flange bolts have even been left out. If the piping is located so that it may easily be inspected, leaks can be detected. Under some conditions, air leaks are not easily visible and considerable loss may result unless particular care is used in hunting them down.

Leaks mean not only direct loss, but the indirect losses due to leaks may be many and expensive. The drip from leaks may fall upon brickwork, concrete and other piping, causing damage. Moisture leaking upon pipe covering reduces its insulating value very materially, and shortens its life.

Scale

Scale is likely to form almost anywhere in steam and hot water piping. It is particularly troublesome in feed water systems and other piping carrying water at high temperatures. The amount of scale depends upon the character of the water as well as upon the conditions of operation.

In feed water systems in which temperatures run up toward 200 deg. and over, certain minerals in solution and suspension settle upon the bottom of the pipes and, if allowed to remain sufficiently long, will harden and stick to the pipe. In time this scale becomes sufficiently thick seriously to reduce the capacity of the pipe. All pipe in which such deposits are likely to occur should be arranged for easy inspection, blowing out and, in some cases, mechanical cleaning. It is in line with good practice to install such piping with a sufficient number of flanges or, in the case of small pipe, of high grade metallic contact unions, to make it easily and quickly renewable.

High velocity of the liquid through the pipe is effective in keeping down the amount of deposit that clings to the surface. Feed pipes are commonly figured for velocities of 300 to 400 ft. per minute.

Corrosion

As has already been stated in connection with boilers, corrosion is ordinarily due to the presence of dissolved gases in the water. At places where air pockets may form, such gases may collect as they are separated from the water and, in the presence of the moisture, attack the metal. Such corrosion takes place over limited areas and often takes the form of pitting. Internal pitting is much deeper near mill scale than elsewhere. Ordinarily, however, corrosion in pipes spreads over a considerable amount of surface and may be detected from a careful examination of the surfaces themselves or by a collection of oxide at some point in the pipe. Sometimes the water itself is given a rather distinctive color.

Internal corrosion of cold-water pipes is usually so slow as to be negligible. Hot water heating systems invariably show no corrosion to speak of after 35 to 40 yr. of service. On the other hand, hot water supply

TABLE III. EFFICIENCIES OF MAGNESIA COVERING 2 IN. THICK

Size of Pipe Inches	Temperature Difference between Steam and Air					
	50	100	200	300	400	500
2	81.3	83.3	85.9	88.2	90.2	91.7
3	83.6	85.2	87.7	89.6	91.4	92.9
4	84.8	86.4	88.7	90.5	92.1	93.4
5	85.7	87.2	89.3	91.0	92.5	93.8
6	86.3	87.8	89.8	91.3	92.8	94.0
8	87.0	88.4	90.3	91.8	93.1	94.3
10	87.6	88.9	90.7	92.2	93.4	94.5

systems, which operate at about the same temperatures and using the same water, often last less than half that time. The hot water heating system carries only the oxygen contained in the original supply of water and in the small amount of make-up water, while the hot water supply system is being continually supplied with new water practically saturated with oxygen.

Internal corrosion may be prevented for a time, at least, by internal coatings. In boiler plants, the ordinary precautions used in connection with the boiler water will usually serve for the piping.

Covering

ALL PIPING carrying fluids at a high temperature should be covered, as properly applied, good commercial covering will prevent from 75 to 95 per cent of the loss due to radiation. It has been found that bare pipe radiates approximately 3 B.t.u. per hour per square foot of exposed surface per degree difference of temperature.

In Table II will be found the radiation in B.t.u. per foot length of pipe for various sizes and various thicknesses of covering, also for bare pipe. These data are based upon tests made at 160 lb. pressure and are the average per degree for the temperature difference between 60 deg. air and the temperature corresponding to 160 lb. pressure.

In Table III are given efficiencies for magnesia covering 2 in. thick. It should be noted that efficiencies increase not only with the increase in the size of pipe with the same temperature difference, but also increase with the temperature difference for a given size of pipe.

All magnesia and asbestos covering should be covered with canvas or other strong material and should be kept in good repair. At such places as are exposed to injury by such things as trucks and crane hooks some form of metal or wooden protection should be provided. It is advisable to paint the outside of the covering, as moisture injures pipe covering. The destruction may be slow, but sooner or later it will become evident. Pipes should be perfectly tight before they are covered, and no water, oil or other liquid should be allowed to come in contact with the outside of covered pipes.

Hot water, exhaust lines and the like may be covered with 1-in. covering.

Some pipe coverings give good results at moderate pressures and temperatures but contain 20 to 22 per cent of inflammable material. Under high temperatures this will become scorched and charred next to the pipes. The decrease in volume which results allows the covering to sag, forming a space which, though it may be only ⅛ to ¼ in. thick, will allow convection currents to form carrying heat to any openings in the joints. Coverings must first have good insulating quality, fit the pipe, be light, and yet have sufficient strength.

Diagram and Color Scheme

A DIAGRAMMATIC layout of the piping in the plant should be made if practicable and a copy of it posted in both boiler room and engine room. It should be sufficiently large to be clear. Each line and valve should be marked either upon the part itself or by number in connection with an index table on the drawing. The equipment controlled by the various valves and pipes should be clearly indicated.

A scheme for the purpose of ready identification of piping systems is that embodied in the A. S. M. E. Report of Committee on Identification of Power House Piping. This committee suggests that colors shall be used on valves, flanges and fittings only, the piping proper to be painted to conform to the color scheme of the room. Its recommendations are as follows:

Steam division	a—High pressure—white.
	b—Exhaust system—buff.
Water division	c—Fresh water, low pressure—blue.
	d—Fresh water, high pressure, boiler feed lines—blue and white.
	e—Salt water piping—green.
Oil division	f—Delivery and discharge—brass or bronze yellow.
Pneumatic division	g—All pipes—gray.
Gas division	h—City lighting service—Aluminum.
	i—Gas engine service—black, red flanges.
Fuel Oil division	j—All piping—black.
Refrigerating system	k—White and green stripes alternately on flanges and fittings, body of pipe being black.
Electric lines and feeders	l—Black and red stripes alternately on flanges and fittings, body of pipe being black.

Under the best conditions of operation and maintenance, piping will deteriorate with resulting misalinement, leaks, sags, corrosion, or similar troubles. Periodic inspections should be made covering all such items and at such times it is well to consider improvement.

Valves

Pointers on Selecting, Installing and Maintaining

VALVES are to steam, air and water systems what switches are to electric systems. They not only control in a large measure the operation, but they largely control the safety of the plant. They should be of high grade material, carefully chosen for the service in which they are to be placed, and kept in the best of repair. Valves should never be permitted to leak. Leaking means unequal wear on the disc, and cutting. This question of tightness, while affecting all valves, applies particularly to those valves which are normally closed or which remain closed over considerable periods of time. The most conspicuous cases of this are the blowoff valve and the safety valve, which require probably more attention than any other valves in the power plant.

Corrosion in the valve parts and especially the valve disc and seat may usually be prevented by proper choice of metals. The manufacturer can give good information along this line. Sticking may result from corrosion or incrustation, causing a sort of cement action

between the disc and the seat or on the plug or stem. This is more likely to occur with gate valves or plug valves than with other types. Cutting of discs and seats by moisture or dirt in the steam or liquid may occur in valves which are partly open and in extreme cases when they are fully open. Gate valves should never be used for throttling purposes either on steam, air, or water. They will cut and they may chatter. Sticking may be due to tight screwing up of steam packing, especially if packing is worn down to an insufficient amount.

By choosing proper material, the above difficulties may be prevented or greatly minimized. Discs for globe valves are made of a great variety of materials. Soft composition or babbit for low pressure water; rubber composition or babbit for cold water up to 250 lb. pressure; semi-hard composition, babbit, brass, or bronze, for hot water and boiler feed; hard composition or hard bronze for steam up to 150 lb. pressure; nickel and alloys high in nickel for highest steam pressures and superheated steam. Valve seat rings should be made of non-corrosive metal of characteristics similar to metal discs.

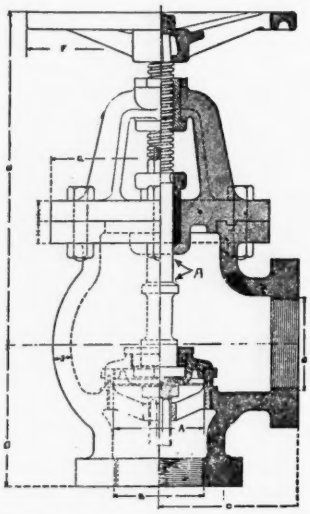


FIG. 1. SECTION OF ANGLE VALVE SHOWING PACKLESS FEATURE

Leaks

From a reliable source comes the statement "a ½-in. diameter valve stem leaking all around the stuffing box will blow about 40 lb. of steam per hour, with 100 lb. pressure in the valve." It is easy to estimate what this sort of thing does to the coal pile in a month or a year.

Leaky valves should be repaired as soon as possible after the leak is discovered. Leaks in valves may sometimes be due to the distortion of the valve seat caused by the weight of piping carried by the valve. There should be supports near all valves. Sometimes valves are seriously strained when being assembled into the piping by carrying the twist through the body of the valve. The wrench should always be applied to the end at which the threaded connection is being made.

When lead or similar substance is used in making up joints, it should always be put upon the entering part. The excess is then forced back upon the outside and can be wiped off instead of being pushed inside where it may cause trouble on valve seats or at other points.

If the threads on pipe are run back too far trouble may result, especially in the case of light weight valves, due to the pressing of the pipe against some part of the valve in such a way as to cause distortion of the seat. Valves on high pressure lines of 6 in. diameter and larger should be provided with a bypass. The bypass not only makes it possible to operate the valve more easily but reduces wear of the valve due to the fact that the main valve may be virtually balanced while being opened and closed.

All dirt and scale should be rapped and scraped from pipe, valves and fittings before erecting and all new work and repair work should be blown out, with live steam if possible, before being put into service.

One cause of leaky safety valves is the strain of the body due to the weight of the pipe carrying blowoff to roof. This condition has been overcome in many cases by supporting the weight of the pipe independently and making some form of slip joint between it and the valve.

For high pressure superheated steam steel body gate valves with complete monel metal trim seem to be the standard. Even with these certain troubles are experienced when temperatures are around 700 deg. F., one of which is the cutting through of the steam between the seat rings and the valve body. Another is leakage at the connection of the bypass to the main valve body due to the expansions resulting from these extremely high temperatures. In some cases there has been leakage of steam through the bodies of these valves after they have been put into service. This has brought out the suggestion that they be tested with superheated steam before installing since the hydraulic test seems to fail in this regard.

Operate all valves slowly. Observance of this suggestion will not only result in keeping the valve in better repair but in many cases saves wear and tear on piping and machinery. No wrench or bar should be used on hand wheels. If a valve cannot be turned in the ordinary manner, it is likely that dirt is jammed on the seat or that the packing needs removal. Remove the bonnet if practicable and find out the trouble. Valves 6 in. in diameter and over should be provided with a bypass valve.

Packing and Regrinding

Careful attention should be given to packing and it should be inspected frequently. If leaky packing cannot be made tight by a moderate amount of screwing up it should be renewed at once. The need for renewal of packing is not always indicated by leaking, but the position of the packing nut or packing sleeve will often indicate the need of new packing. It is best to follow the advice of the manufacturers in the choice of material for packing.

Choose valves with a generous packing space, especially in the matter of depth, which means a given tightness for less pressure, and with a non-turning gland if possible. Nuts on packing studs should be tightened evenly to avoid binding on the stem. For valves which stand full open much of the time the packless type is to be recommended. In Fig. 1 the packless feature is shown at A and the packing gland

is non-turning. Never install valves with stems downward.

If service is of such character that regrinding is likely to be necessary, "regrinding" valves should be specified. A check valve with provision made for regrinding is shown in Fig. 2. With valves of moderate size, arranged for regrinding, all that is necessary is a little graphite or oil and graphite and brace with screwdriver. In the case of large valves, returning in the lathe or in some cases replacing of disc and seat are necessary.

Emergency Operation

Emergency operation of valves is a matter receiving much attention at the present time. Both hydraulic and electric methods of operation are used and have been a success up to a certain point; but there is no case on record where either the hydraulic or electrically operated valve above 12 in. working on high pressure steam has successfully closed when operated in an emergency with full pressure steam on one side and with the other side open to atmosphere through a large break or equivalent. There is a general demand for some type of valve that will shut off steam from the turbine room in case of serious accident to the turbo units or piping. The developments up to the present time are largely on gate valves and it is believed that valves up to 10 or 12 in. can be successfully closed under emergency conditions. For sizes larger than 12 in. butterfly valves are proposed and experiments are now being made with them. The most important question in connection with this development is the speed with which escaping steam should be shut off in the event of a pipe or fitting fracture, which would cause a large volume of steam to blow to atmosphere. Instant stoppage would likely cause damage in the line back of the break due to reaction.

Safeguards

Many accidents have been caused by the opening or closing of a valve at an inopportune time. This makes it necessary to mark valves which must remain undisturbed during the performance of some particular work.

In the preceding section, the value of having an up-to-date diagram showing all piping was suggested. This, in connection with a distinctive color scheme, such as that recommended by a committee of the A. S. M. E. which is included in the preceding section should be of much value in connection with the safety of lives and property. A complete knowledge of the piping layout of a plant and the ability to put the hands quickly upon any desired valve has been of inestimable value in many an emergency.

Under routine running conditions there is need for locks, and tags and signs warning of danger, or definitely prohibiting manipulation. When the more unusual work is being done such as repairing, cleaning of boilers, and installing of machinery which may be going on at one point in the plant today and at an entirely different point tomorrow or next week is under way, the situation is special and each case needs individual treatment. The men doing such jobs set the valves as required and it is necessary that they be left as set until the job is finished.

Safeguards may be of various kinds. Warning tags may be attached to the valve wheels or stems. Wheel covers, which usually take the form of a metal box, which is hooked or sometimes locked around the valve wheel, protect the valve against manipulation. Another method which accomplishes about the same results as the wheel covers is the removal of the valve handles. In this case it is necessary that the spindle of the valve and handle or wheel shall be arranged to make this possible. In those cases in which the inopportune opening or closing of a valve would be unusually dangerous, signals of conspicuous character are employed. This of course is similar to the tag system only that the danger element is more clearly emphasized.

In this connection, mention may be made of the necessity of safeguarding such protective and controlling devices as safety valves, relief valves, water columns and gage glasses, pump governors, alarms and the like against being reset, blocked or otherwise tampered with by unauthorized persons. The method to be employed must be chosen to fit the case, a padlock, a seal, an upset bolt or rivet, a warning sign, depending upon the element of danger involved, the form of organization and the personnel.

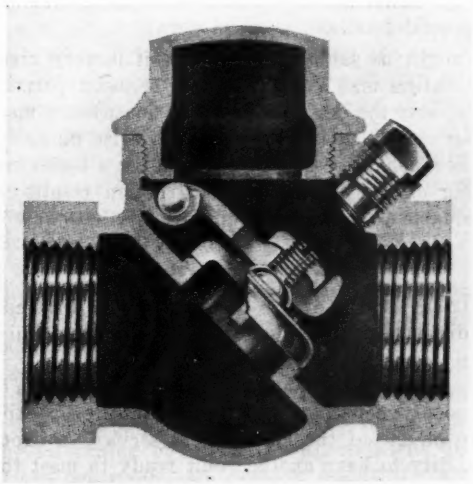


FIG. 2. CHECK VALVE WITH PROVISION FOR REGRINDING

Automatically controlled valves, which are used for maintaining water level, driving pumps, and similar service, operate largely by throttling and the seats are apt to be worn or cut after relatively short service. For this reason they should be examined frequently and seats and discs renewed or reground when necessary.

It is usually recommended that valves on high temperature lines be covered. Plasters are on the market which may be used for the smaller sizes, but, for large valves, coverings made of suitably shaped sections are preferred. Sheets and blocks may be purchased in various sizes up to 24 by 36 in. and thickness from ½ to 4 in.

Regular inspections of the condition of all valves should not be neglected. When it is considered that the failure may cause great damage to property and danger to life the necessity of knowing the exact condition of every valve in the plant and of keeping them in as perfect condition as possible is realized. Leakage, corrosion, condition of joints, packing, and covering should be given attention and dated records kept of all inspections.

Operation and Maintenance of Steam Turbines

STARTING UP, RUNNING, SHUTTING DOWN, AND STANDING, EACH MAKES ITS OWN DEMANDS ON SKILL AND ATTENTION. BY P. W. THOMPSON

INASMUCH AS CONTINUITY of service in steam-electric generating plants is not only expected but demanded, it is highly important that the turbine which plays a leading part in the present day power plant be given considerable thought as to its proper care and correct operation. Unless this is done, trouble is sure to follow in the form of a break down of the machine or a decrease in its economy.

Certain types of turbines when first installed need special care and attention during their first period of use but it is not the intention to enumerate here any of these special details.

It might be said, however, that it is very much to the operating man's advantage, if occasion permits, to watch closely the details of construction when a machine is being assembled in order to familiarize himself with them as much as possible. By so doing a better understanding of the mechanical construction results which is a valuable asset to correct operation.

OPERATION—STARTING UP

THE OPERATION of the turbine may be divided into four distinct parts or periods: starting up, running, shutting down and the idle period.

The necessity for starting up a turbine follows either from some emergency such as the failure or expected failure of one of the machines in service, or from the desirability to have another unit ready to meet the demand for increasing station load.

Under normal conditions of starting, a thorough visual inspection of the turbine and its auxiliaries should be made to be sure that everything is in readiness. The procedure which is followed in the actual starting of the turbine is dependent upon the type and size of the machine. With small units there is practically nothing to do except open the throttle and bring the machine up to speed, but with larger units, especially the horizontal type which operates at higher speeds than the vertical type, there are many details to be followed and the proper sequence of these may depend upon the design and arrangement of the turbine and its auxiliaries. A certain sequence should, however, be followed which is determined by necessity or trial to give the best results, and the same sequence should always be followed as closely as possible if the best conditions are to be obtained.

One of the greatest difficulties in starting up a turbine is its tendency to vibrate at certain speeds. This vibration may become so excessive as to become dangerous, necessitating the shutting down of the machine. Usually this is caused by the unequal heating of the rotor, casing, or bearing supports which tends to throw the machine out of line due to the unequal expansion. If the vibration becomes excessive, the only remedy is to shut the machine down and let it stand long enough for the temperature of the parts to equalize somewhat and then start up again. The rate at which a machine is brought up to speed may have considerable effect on the proper equalization of temperature of its parts, so it has been found advisable, in starting very large high speed horizontal machines, to determine by trial the rate of bringing up to speed for best results and then always increase its speed at the same rate each time it is started. This operation is simplified by using a hand tachometer on the end of the shaft and adjusting the throttle to give speeds in accordance with the predetermined schedule.

Investigations have been made of the temperatures at points inside the turbine casing and low-pressure end bearing support under different conditions of starting which show that varying the sequence of starting up operations causes different temperatures in the exhaust end of the turbine. A certain sequence and time interval in starting up operations may give good results with one type or one particular machine, yet if followed on another may fail to give as good results. Further investigation and experiments may throw more light on this subject.

Using superheated steam or even saturated steam on the low-pressure shaft packing of large turbines, unless with care, will sometimes heat up the bearing support enough to throw the turbine slightly out of line with the usual result of excessive vibration in starting up. In machines equipped with a water seal on the low-pressure end it has been found that the turbine can be properly sealed at that end by using water at about 30 lb. pressure without any steam, during the period of bringing the vacuum up on the turbine prior to opening the throttle or throttle bypass valve.

Mechanical or electrical signal systems are in general use between the turbine operator, the switchboard operator, and the boiler room. These play an important part in co-operating the activities of the three departments.

After the machine has reached its running speed and the governor has closed the admission valves, it is well not to open the throttle any more until after the unit has been synchronized with the station bus. This facilitates synchronizing and does not put full steam pressure on the admission valves until the machine is ready to take load.

Under normal conditions, it is not good practice to load the turbine up too fast, as severe temperature stresses may result. Generally speaking, the load should be increased slowly to about 25 per cent of the turbine capacity within 20 to 30 min., after which the machine should be able to take care of the normal demand imposed upon it. Of course there are emergencies when it is necessary to load the machine immediately, but this imposes serious stresses and is to be avoided.

RUNNING PERIOD

DURING THE running period, a systematic routine inspection should be followed so that should any trouble or unusual conditions arise these will be discovered and promptly remedied. The lubricating system requires close observation as well as the quietness and smoothness of operation of the unit as a whole.

For the purpose of record, certain observations should be taken and recorded periodically, usually at hourly intervals. These observations should consist of the important information regarding the conditions under which the turbine is operating, such as, the pressure and temperature of the steam at the throttle, the first stage or head pressure, the vacuum which is reduced to back pressure by subtracting the vacuum gage reading from the barometer reading, the load on the turbine, and the oil temperatures from the several bearings. In many plants, a special form turbine log is used, one for each day, which is provided with space for special information such as the time of starting and stopping, and any pertinent remarks regarding special or unusual conditions of operation.

In order to operate with the maximum economy when two or more turbines are required to supply the demand upon the station, the load must be properly adjusted between the machines so that the total steam supplied per hour shall be a minimum. When there are only two or three machines on at the same time it is not a difficult matter, by using the water rate curves determined by test, to calculate the proper relative loading for a minimum total steam consumption; but when there are a greater number of machines this determination of the exact load to be carried on each individual turbine becomes more difficult and cannot be satisfactorily accomplished by observation of the water rate curves. One graphical method is to plot on one sheet the rate of increase of the steam consumption of the several machines and then load the turbines so that the load carried on each machine corresponds to the same rate of increase of its total steam consumption. This method requires considerable work in the preparation of the curves but is very satisfactory and gives the desired results quickly once the curves are available.

Shutting Down and Standing Idle

Aside from an emergency, it is usually desirable to shut down a turbine when the total steam consumption of the plant would be reduced by taking one machine off the line. Remembering that continuity of service is paramount, it is not, however, advisable to reduce the number of turbines on the line below that which would permit of the complete loss of any one of them without a resulting break in the service.

When the unit has been disconnected from the station bus, the turbine throttle should be immediately closed. On large horizontal high-speed turbines the high and low-pressure shaft packings should be kept sealed until the machine has stopped rotating. Failure to do this will result in loss of vacuum and the rapid revolution of the turbine rotor in the relatively denser medium may develop enough heat to cause serious temperature stresses.

If the turbine has been in continuous operation without shutting down for a week or more it is a good plan to test out the emergency or over-speed governor at this time. A record of the speed at which this governor acts should be entered on the turbine log. The atmospheric relief valve should be operated also to make sure it is free and, if the turbine is equipped with a vacuum breaker, this can also be tested.

When the turbine has come to rest and its auxiliaries have been shut down, the turbine should be wiped clean and everything should be put in readiness for running when needed.

It is usually a difficult matter to keep throttle valves tight enough to prevent considerable steam leaking out into the turbine when it is standing idle. If the throttle valve leaks excessively on horizontal type turbines, steam will flow into the turbine and heat the upper part of a casing and rotor, which may cause unequal expansion with a resulting trouble due to vibration when starting up. This can be remedied to a certain extent by installing an atmospheric blowoff connection located between the throttle valve and the admission valves which can be left open, thereby allowing the steam to escape. A better method, however, is to close the line stop valve just ahead of the throttle valve, but if these are located some distance apart, such procedure may be inadvisable owing to the length of time required in cutting in this section of steam piping between the stop valve and the throttle when it is desired to start up the turbine.

Owing to the great weight of present day large turbines we usually find a gradual settlement of the foundation. If this settlement is uniform, it does not matter, but in case the settlement at one end of the turbine becomes greater than at the other end, the alinement of the unit is impaired. It is therefore advisable to check the settlements of the turbine base supports at regular intervals, say every month, and a record should be kept of these settlements so that any trouble which might result from this cause can be remedied before any real damage occurs to the machine.

Condition of the oil piping should be watched closely so that no obstruction is permitted to form which might reduce the oil supply to any of the turbine bearings. If the oil piping is provided with sufficient openings, it may be blown out with steam or compressed air whenever necessary; if not, the piping must be taken off and cleaned internally. If the turbine has oil-cooled type bearings, the machine is equipped with a surface oil cooler. A deposit will gradually form on the tubes of the oil cooler which will reduce its effectiveness and when the temperature of the oil leaving the cooler rises to what is considered a dangerous point, the cooler must be cut out of service and cleaned.

Condenser

No doubt many engineers fail to realize the extent to which the economy of the turbine is affected by even a slight reduction in the vacuum. Particular effort should be made at all times to discover and immediately repair any air leaks into the condenser or the exhaust casing of the machine so that the maximum obtainable vacuum may be maintained. When a displacement air pump is used for the removal of air from the condenser, a simple home-made gasometer connected to the pump discharge is a good means of detecting air leakage, and routine tests should be conducted for the purpose of determining the presence of excessive quantities of air.

When opportunity permits, an occasional general inspection of the turbine should be made, particularly of those parts subjected to wear and severe stress. Thus it is often possible to discover worn parts or weaknesses before any serious break-down occurs and such procedure tends toward a longer life and smoother operation of the turbine.

The Steam Turbine

Starting

IF the steam turbine is equipped with an auxiliary oil circulating pump, this should be the first thing started when putting the turbine into service. Examine each bearing in turn and after making sure that oil is flowing steadily at each point, turn cooling water on the oil cooler, open all steam drains, and start the circulating water through the condenser.

Next open the throttle valve as much as can be done without giving motion to the rotor and let the steam blow through for a sufficient time to heat all parts thoroughly and uniformly. Excepting in the case of quite small turbines, it is well to allow a full 15 min. for this.

When the machine is properly warmed up, sufficient steam may be admitted to turn the rotor slowly, say not to exceed 100 r.p.m., and, if a large turbine, it should be run in this manner for 10 min. or longer.

While the turbine is idling, water may be admitted to the glands in sufficient quantity to seal them, but not in great excess. When operating non-condensing, the drains from the sealing spaces should be left open, but when condensing they should be kept closed.

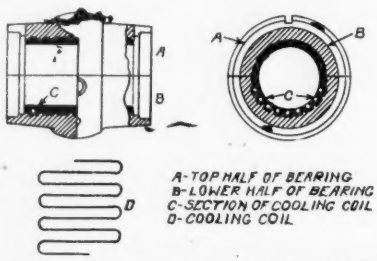


FIG. 1 TURBINE BEARING FITTED WITH COOLING COIL

More steam may now be admitted and the rotor gradually brought up to speed. It is well to watch the action of the governor as the turbine works up toward full speed to determine the moment at which the governor goes into control and thus makes it safe to throw the throttle wide open. While bringing the rotor up to speed, turn off the auxiliary oil pump and make sure that the direct connected oil pump takes up the circulation of the oil.

When the turbine operates condensing, the next step is to build up the vacuum. It is best not to build up the full vacuum while the turbine remains unloaded due to temperature conditions, but usually it may safely be brought up to 25 in. of mercury.

Next throw in the field current and adjust the field rheostat; if synchronizing is necessary, it may be done at this time.

The turbine is now ready to carry load. Throw load on gradually and as soon as it has been raised to about 10 per cent of normal the vacuum may be increased to its full amount.. In central station practice it is customary to take an hour or more to bring the larger turbine units into operation, load being increased very gradually.

Service

WHILE a turbine is in operation watch should be kept of the flow of oil, and if decrease in flow to any bearing is observed, the auxiliary oil pump should be immediately started.

It is advisable to operate under the steam and vacuum conditions for which the turbine was designed, since a reduction of the vacuum may throw the last rows of blading out of service and they may not only fail to assist but they may even retard rotation. On the other hand, an increase in the amount of vacuum is of little value since the blade areas are not sufficiently large to accommodate the largely increased volume of steam resulting from the greater vacuum. Ordinarily an increase in the steam pressure will bring about a small increase in economy.

The drop usually allowed between the last row of blades and the condenser is 1/10 to 2/10 in. of mercury. An increase of ½ in. in this drop usually means an increase of approximately 2 per cent in the water rate, which indicates the importance of small variations in vacuum conditions and emphasizes the necessity of watching operation and adjustment closely. It is also desirable to maintain the superheat and steam pressure for which the turbine and piping are arranged, since a drop of 7 deg. in superheat represents an increase in water rate of 1 per cent at 50 deg. superheat, and 13 deg. drop means one per cent increase in water rate at 200 deg. superheat.

The steam flow meter in connection with the generator output affords a ready means of comparing the operation at one time with that at another and with the standard of operation to be expected; any marked divergence from the standard is good reason for investigating the causes. When the proper economy of operation is once established, with proper maintenance and operating attention, equally good results can be expected during years of service.

Continuous record of the condensed steam is a further valuable factor in the record of operation.

Stopping

WHEN shutting down the turbine, first start the auxiliary oil pump slowly, reduce the load gradually, and when it has fallen to about one-tenth normal reduce the vacuum to about 25 in. of mercury.

Next pull the trip levers which close the throttle valve, speed up the auxiliary oil pump and follow by gradually reducing the vacuum.

When the rotor comes to rest shut off the flow of water to the glands, stop the auxiliary oil pump, shut off the cooling water and open all the steam drains. Finally, close the throttle valve, oil the valve stems, and hang up the trip.

Lubrication

MOST TURBINES are provided with oil circulating systems, a common arrangement being to employ a positive pump which draws the oil through fine screens from a central drain-collecting reservoir and forces it into an elevated storage tank whence it is distributed to the various bearings by gravity. The N. E. L. A. recommends that the pressure in the oiling system be

low enough to permit lubrication from an oil distributing tank located near the roof of the building. Some turbines have two complete pumping units, one driven independently by steam, the other mechanically from the turbine. Where there is no independent pump the elevated tank should be sufficiently large to store all the oil required for starting and stopping.

Heat is carried away from the bearings by the oil and the oil temperature is reduced by passing it through a water-cooled receptacle. In some cases it has been found advisable to increase the cooling rate by circulating water through the bearings, Fig. 1 showing such a bearing with a "back and forth" cooling pipe cased in the babbit.

Since dependability is absolutely essential and since the oil must pass through small pipes and flow-adjusting valves, it is necessary to keep the passages free from dirt and lint, the strainer washed and the reservoirs free from sediment.

Some water always gets into the circulating oil and a good percentage of this with other foreign matter settles into the bottom of the oil tanks, whence openings make possible drawing off most of it. This should be done at regular intervals as a part of the routine and occasionally emptied and thoroughly cleaned. The oil should be reclaimed, the process commonly employed being similar to that described under lubrication for steam engines. New oil should be added frequently to maintain the proper quantity in the system, since there is a gradual depletion caused by evaporation and escape of oil.

Use only absolutely pure mineral oil chosen for its suitability for use in steam turbines. Consider the oil from the point of view of service and not altogether from its physical characteristics. Some heavy mineral oils will emulsify with water and cannot be used in this service for that reason. It may be advisable in some cases to use different oils at the two ends.

Something is wrong when the temperature of the oil flowing from a bearing rises to 150 deg. F. The proper range of temperature may be taken as 110 to 140 deg. F. Governor levers and valve spindles and levers should be oiled daily and valve pistons at the time of shutting down.

Water for use in the oil cooler should be clean and cool.

Water for sealing must be pure since otherwise it may injure sealing rings and bushings. Condensed steam from the condenser is usually recommended for this purpose. The water pressure at the glands is commonly limited to from 10 to 15 lb. per sq. in. and the temperature to 100 deg. F.

In some lubricating systems, the bearings are kept flooded with oil. This has the advantage that the bearings may be kept cooler especially during hot weather, or in turbine rooms in which the temperature is normally high; also the wear on the bearings is practically nothing. By virtue of the larger passages in this arrangement there is less likelihood of clogging of the flow of oil with accompanying troubles from hot bearings.

The cooler should be taken out of service occasionally and thoroughly cleaned. If it is found that the oil leaves the heater at a temperature about as high as that at which it enters, the heater should be cleaned at the earliest opportunity.

It is a good plan to arrange the water connections to the oil cooler so that the water may be run through in either direction. By reversing the direction of the flow of water a good part of the loose dirt which has collected will be washed out of the cooler. Also it has been suggested that when compressed air is available connections be made to both of the water connections to the cooler. This makes it possible to agitate the water and thus remove collected dirt much more effectively. A sand blast, easily improvised if necessary, is useful to cut out any matter that sticks and makes it possible to get at every bit of the surface. If the inside of the oil tube becomes fouled, both air and live steam have been found effective for cleaning. Washing with lye in warm water may be necessary when air or steam fails. It is imperative that the lye be washed out thoroughly before returning the cooler to service.

Packing

Leaks through the shaft packing at the steam end are unsightly and for this reason, if for no other, this packing should be kept in good order. The packing at the exhaust end should be given just enough water to maintain a proper seal between the water chamber and the outer end of the rings. Leaks at this joint are costly for the reason that they admit air to the exhaust spaces and thus throw additional work upon the pumps. Air in the exhaust system sometimes forms air pockets in

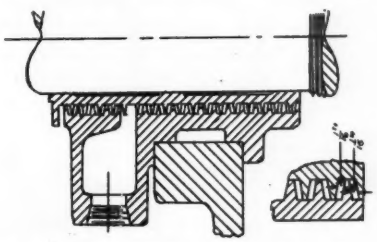


FIG. 2. LABYRINTH TYPE OF GLAND

the condenser, thus reducing its effectiveness and infiltration of air at this point may contribute to this trouble.

Leakage of steam through the packing between the upper and lower halves of the casing is easily detected and can be taken care of by proper packing and tightening of bolts. Leaking of air through this same joint into the vacuum part of the turbine is less easily detected. Such leakage may be prevented by coating the outer edges of the joint with a suitable paint when the parts are put together. If the casing be tested for tightness while the paint is fresh, the paint will be drawn in at any place where there may be leaks and, unless the openings are unusually large, will close the leaks.

Nozzles and Blades

Due to the tremendous velocities of steam through the passages some erosion of nozzles and blades is to be expected. Rapid erosion may indicate that the parts are made of improper material but it is usually found that the steam has carried water or dirt. This condition should not be permitted to continue, since it is due to some fault in boilers or piping; a proper remedy should be applied at the source. Carrying over of large slugs of water with the steam may cause serious damage such

as the loosening or knocking out of buckets, sometimes with disastrous results. It is needless to say that the only way to prevent such troubles is to keep water out of the turbines. A well known operating engineer said recently: "These steam turbines will not run on hot water. You probably can realize what will happen to a set of blades traveling 40,000 ft. a minute with compressible steam operating on them at a high temperature, to get a sudden dash of a considerable quantity of comparatively cool, non-compressible water. It is very likely to take the blades off and to set up vibrations."

Valves

The chief thing to be kept in mind in connection with the throttle valve of a turbine is that it must be perfectly tight when closed. It has sometimes happened that sufficient steam has passed the throttle valve to heat unevenly the various parts of the turbine with the result that the shaft has been slightly distorted or the discs or frame warped. Such distortions may cause serious damage on starting up the machine due to the small clearances between casing and rotor, and in the case of a bent shaft, unbalance may be sufficient to cause disaster when the rotor is brought up to speed. As a safeguard against the possibility of such leakage, drains and vents have sometimes been provided between the valve and the casing.

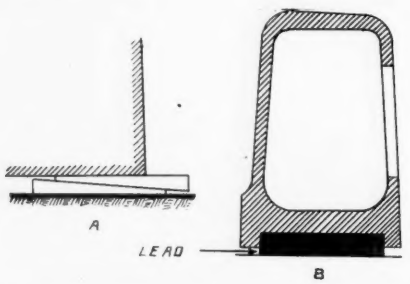


FIG. 3. (A) METHOD OF LEVELING BED PLATE; (B) USE OF LEAD FOR GROUTING BED PLATE

Governor valves which control a number of nozzles should be kept tight so that there is no wiredrawing of steam into the nozzles which are supposed to be closed by the governor. Steam that gets through in this manner is of practically no value for doing work and besides does positive damage by cutting the seats. It is hardly necessary to say that the bypass valve also should be tight when closed, since any steam passing it when closed is wiredrawn from high pressure and largely reduced in pressure with the result that it does not perform as much work as it would if it were admitted at the high pressure nozzle; besides it cuts the valve. This valve should be so adjusted that it opens when steam admitted by the valve is really required to furnish added power and not before. In most cases it should come into action when the steam pressure in the casing just beyond the governor valve is 5 lb. less than the steam pressure just above the governor valve. This adjustment can usually be made on the valve spindle.

Since cast iron "grows" when used in contact with superheated steam, it is well to examine any packing rings that may form part of any valve or of the turbine to make sure that they still have end clearance; otherwise they may not slide freely and thus may interfere with the free action of the valve.

Critical Speed and Vibration

It is impossible to balance a rotor perfectly. At ordinary speeds such as are common in the general run of electric motors and generators, balancing is usually not difficult, and a small amount of unbalance is seldom troublesome. On account of the high speeds usual in turbo-generator units, unbalance often gives trouble even though great care has been taken in construction. It is well known that the effect of unbalance increases rapidly with the speed. If the amount of unbalance remains constant as the speed increases, the effect increases as the square of the speed. If, however, as is usually the case, the shaft deflects more and more with increase in speed, the effect increases more rapidly than the square of the speed. If this effect continued to increase up to the speed necessary for economical operation of the steam turbine, it seems likely that there would be fewer steam turbines in successful operation. Fortunately success is made possible by the phenomenon known as critical speed, or, it might better be said, by a change in relative position of the parts while the machine passes through the critical speed.

If the axis is perfectly straight and the center of gravity of a single disk is slightly eccentric to the axis of rotation, the shaft will bend more and more as the speed increases and the center of gravity of the disk will depart farther and farther from the axis of rotation of the shaft, accompanied by a correspondingly increased pull against the bearings. But finally a speed is reached at which the restraining power of the shaft is overcome and a sort of re-arrangement takes place, often accompanied by a considerable amount of disturbance, in which the center of the shaft takes a position outside of the center of gravity of the disk with the result that the disk rotates very nearly about an axis through its own center of gravity and the bowed shaft rotates around the center of gravity of the disc. With further increase of speed the condition of unbalance steadily improves, that is, the center of gravity of the disk approaches more and more nearly to the axis of rotation. The illustration just given was for a shaft with a single disk; a more complicated arrangement may have more than one critical speed, but it is usually the case that only one critical speed, if any, is passed before the speed of operation is reached.

Marks says: "In the neighborhood of the critical speed a shaft merely undergoes more or less intense vibrations which are generally transmitted to the supporting frame. The deflecting force may be due to some external cause, but it is usually supplied by the almost unavoidable deviations of the center of gravity of the various loads from the center line of the shaft. By reducing these deviations to a minimum by fine workmanship and extremely careful balancing, the vibration at the critical speed may be made scarcely noticeable."

In some cases the disturbance while passing through the critical speed is greatly reduced by increasing the speed rapidly at this point.

Vibration must not be confused with the action at critical speed, since vibration may occur to some extent

at any speed and it is improbable that any machine will operate continuously at its critical speed.

Vibration may be due to any one of a number of causes, the most common of which are: 1, interference of rotor with casing; 2, poor shaft alinement; 3, loose bearings; 4, leaky throttle; 5, scale or dirt on blades; 6, worn or loose coupling; 7, change in operating temperatures; 8, insufficient or poor oil; 9, too close fit in packing rings; 10, electrical unbalance.

1. If the machine is from a responsible maker this trouble is probably due to improper erecting and can be corrected by adjusting for clearance.

2. Considered elsewhere.

3. If too much journal clearance is suspected, find the amount of clearance with a lead wire (see under steam engine). Clearances should be about as follows: 0.008 to 0.012 in. for journals up to 6 in. diam.; 0.015 in. for 7 to 8 in. diam.; 0.020 in. for 9 to 10 in. diam.; and 0.025 in. for larger diameters.

4. Considered elsewhere.

5. Considered elsewhere.

6. The coupling may have loose bolts, or fingers and pins may be worn or shouldered.

7. Owing to the extremely small clearances allowed in some turbines, especially in the stages under high pressures, any decided change in range of temperature between entering and leaving may reduce those clearances sufficiently to cause interference. In most cases,

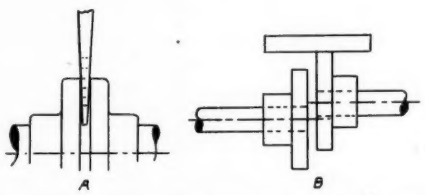


FIG. 4. LINING OF TURBINE AND DRIVEN SHAFT BY MEANS OF COUPLING

the best thing is to operate under or near the temperatures for which the machine was built, even at part load.

8. Considered elsewhere.

9. These rings should not hug the shaft and should not jam. Play of 0.001 to 0.002 in. should be allowed.

10. Electrical unbalance may be due to short circuit or ground in the rotor, which is usually not difficult to locate and repair.

Foundations

Foundations for steam turbines should be rigid but need not be so massive as those required for reciprocating engines. Great care should be taken in leveling them and in keeping them level. Structural foundations and those resting on floors ordinarily require substantial side bracing. It is best to follow the recommendations of the builders of the turbine units with reference to general dimensions as well as in the detailed provisions for holding down. A single rigid foundation should serve for the entire turbo-generator set; it is not good practice to place the steam turbine on a foundation and to place the electric generator on a less rigid extension.

Leveling and Lining Up

One of the chief causes of vibration in turbo-generator units is poor lining up. The two shafts should be level and in line as nearly as possible when running. Owing to the expansion of the turbine casing due to its rise in temperature, it is customary to set the two parts so that the turbine shaft is lower than the generator shaft by an amount equal to this expansion, which, roughly speaking, is about 1/100 in., depending upon the size of the machine and upon the difference between temperature inside and outside of the casing during operation. Leveling up can best be done by wedges in a manner similar to that shown in Fig. 3A. Wedges should be placed sufficiently close together to prevent any sagging of the frame. The space between frame and foundation should be grouted clear around so as to give a continuous bearing. An arrangement of grouting with lead which is neat and retains the grout properly is shown in Fig. 3B.

If the coupling has finished flanges, lining up may be done easily by the method illustrated in Fig. 4. In leveling by this method, one of the parts, say the turbine, is set with its shaft level and in correct alinement and the other part brought into line with it. The taper gage must enter between the flanges the same distance all around and the difference in level can be determined by means of a scale laid across the top of the higher flange as illustrated. Both flanges should be calipered and if there is a difference in diameters proper correction should be made for it.

Reference has already been made to the necessity for heating the turbine slowly and uniformly when starting up, and the possibility of damage due to distortion from unequal heating was mentioned in connection with throttle valves. Distortion may also be caused by the weight of the steam piping upon the casing or by horizontal pressures due to lack of flexibility in the piping. Freedom in the exhaust connection between the casing and the condenser should be provided by means of a flexible joint. With all these provisions properly made, care must be taken that there is no interference of piping and casing with foundations or any part of the building.

Stainless Steel Turbine Blades

Experiments on several materials for steam turbine blades, used in the same wheel so as to secure uniform conditions for all blades, showed that, after 5 yr. of operation, stainless steel, an alloy containing 12 to 14 per cent chromium, had experienced no corrosion, either when hardened, or hardened and tempered. Three other materials, phosphor bronze, nickel bronze and brass, showed corrosion at the inlet edges, all to about the same degree. Mild steel showed corrosion over the entire surface and loss of 1/16 in. of metal at the inlet edge.

Other tests lasting over 3470 hr. of running showed no roughening of stainless steel blades either under high pressure superheated steam or low pressure wet steam, and that for long blades in the low-pressure wheel, subject to vibration, the performance was entirely satisfactory over a 5-yr. period.

Steam Engines

Many Small Details Helpful to Operators

CARE of an engine should be entrusted only to a man acquainted thoroughly not only with its construction, method of operation, limitations, and character of service, but he should know its exact condition at any time as to adjustment and faults. At least once a day the engine should be inspected for running condition with special attention to the action of the governor and of the safety stop if one is provided. The bearings should be watched continuously and felt occasionally throughout the day to make sure that the temperature is not running too high.

Lubrication

Any amount of lubrication is of little value upon surfaces which are not kept clean, smooth, and in proper adjustment.

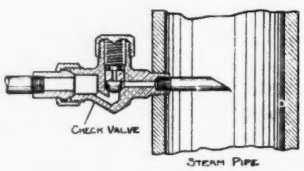


FIG. 1. CONNECTION TO STEAM PIPE FOR LUBRICATING OIL, WITH CHECK VALVE

In lubricating cylinder, piston, valve and other surfaces subject to the action of the steam, the condition of the steam in the matter of dirt and moisture is important. Scoring often occurs in new engines due to sand from blowholes and cored passages, lathe and planer chips, and burrs and grit stuck on parts by oil used in thread cutting. Scale from the piping is sometimes brought in by the steam or water. Caustic soda may be used to excess in the boilers and some of it may be brought into the cylinder and attack packings (and gaskets). Water itself has a bad effect upon lubrication.

Too tight packing of rods and too tight piston rings interfere with proper lubrication. Engines which stand for a time are often washed clean of oil by the water which has collected in various pockets and they groan in protest, sometimes for many minutes, until the regular oiling system has caught up or until someone gives them a generous dose of lubricant. Valve surfaces often wear unevenly, due to the presence of hard places in the metal, and this causes excessive pressures over the relatively small bearing areas which cannot possibly be kept lubricated and which will cut eventually.

Oil should be carefully chosen to suit the conditions and should be kept clean. Sight feed lubricators which operate by gravity pressure require careful attention to keep sufficient flow on the one hand and to prevent waste of lubricant on the other hand. The glass of sight feed lubricator should be kept clean by swabbing the inside with a little carbon oil or turpentine, taking care to leave no lint in the tube. Use a wooden stick in doing this as metal may break the glass, and keep extra glasses on hand. Keep needle valves and all passages free from dirt.

Force-feed lubricators in which a number of outlets are fed from one pump need constant attention to insure proper distribution of the lubricant and should always have sight flow attachments on each outlet. The latest developments in cylinder lubrication have, for each point to be lubricated, individual plungers to force the oil, sight flow indicators, impulse with every stroke, and they also provide a check valve close to each outlet in order to insure the delivery of a definite amount at each stroke of the engine (Fig. 1). When feeding oil into the steam pipe in any system of lubrication the oil should be delivered into the steam current and not against the inside surface of the pipe.

In medium and large plants 1/5 gallon of oil per month per hp. ought to be high and with the best systems of lubrication this should be reduced easily 50 per cent or over.

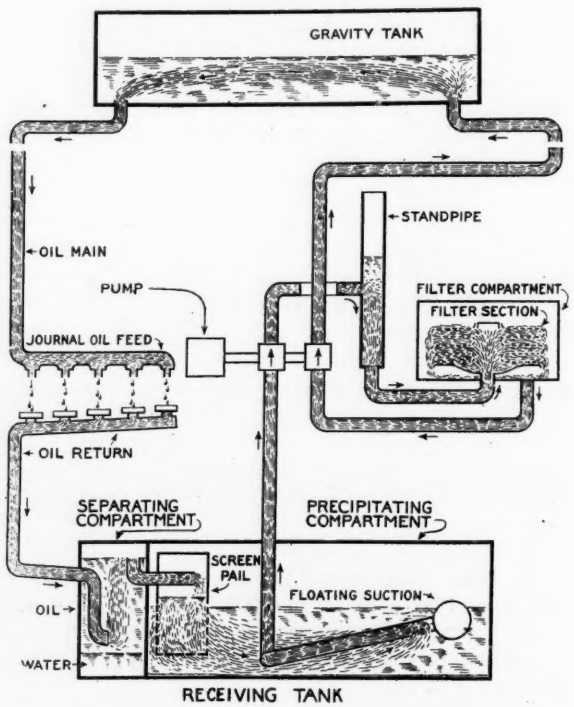


FIG. 2. SCHEMATIC LAYOUT FOR CONTINUOUS OILING SYSTEM

Irregularity and stoppage of flow in gravity sight feed lubricators due to dirt and lint in the oil or left in the wiping may occur at any moment and trouble is likely to follow soon afterward. Ring oiling serves excellently for bearings when there is clean oil in the reservoir and when chains or rings do not stick.

Probably the most satisfactory method of lubricating engine bearings is the flooding or continuous flow system in which the oil is kept in constant circulation as indicated in Fig. 2. In this system, the oil is used over and over. These systems clean the oil by a process of heating, setting, filtering and skimming. Tests on oils

which have been used for months show that the lubricating qualities of the oil remain practically unchanged.

Due to mechanical considerations, various special equipments have been developed for the lubrication of eccentrics, crankpins, crosshead-pins, and guides which are satisfactory on the whole when given the proper attention. The splash system, still much used for high speed engines, has much to recommend it but sometimes fails to throw oil where it is badly needed. Such a fault may often be remedied by provision of an oil cup or other oiling device at the point needing it.

Hot Boxes

When trouble of this sort is discovered the first thing to be done is to loosen the bearing and apply oil freely. After the bearing has cooled off, take up the lost motion, making the adjustment slowly and taking great care not to come up too far and start the trouble all over again. If the bearing is hot enough to burn the back of the hand (about 150 deg.) it is much better to use cylinder oil for cooling since it maintains its body at this temperature. Avoid using water if possible, since, while it does cool the journal effectively, it does not lubricate and in addition it washes off any lubricant that may still cling to the bearing. But if heating remains excessive, and it is necessary to keep the engine in operation, a stream of water on each end of the bearing may make it possible to run until shutting down time.

If it is found necessary to pour the water directly on the wearing surfaces, lard or a similar oil or lard oil and petroleum should be put on with the water. Animal oil adheres better to a wet metallic surface than does petroleum oil alone. Good results have been obtained with a mixture made of 1 part of yellow soap, 4 parts of water, and 5 parts of engine oil, which lubricates, cools, and washes out grit and dirt; it should be followed by an ample supply of clean engine oil. There is danger when putting cold water on a bearing of cooling the box suddenly, causing gripping of the shaft or cracking of the shell; for this reason apply the water in such manner as to cool both the journal and the shell.

After shutting down, the wearing surfaces should be examined. Moderate overheating may not call for more than a little light scraping with particular attention to the oil grooves.

Sometimes the heating is so severe that it is necessary to shut down at once and in such cases refitting of the journal may be necessary.

When a babbited bearing runs hot, follow the directions just given and slow down the engine; but do not stop it, since further trouble will be caused by the adhering of the bearing to the journal.

Packing

With machine parts of correct form properly assembled, almost any conditions of pressure and kind of fluid may be kept tight; with poorly made or worn parts and poor alinement, tight packing may be almost or quite impossible.

Hard metallic piston packing, although rather high in initial cost, gives good service and is long of life. It is best adapted to engines using dry and saturated steam and similar service. Misalinement of piston rod is usually permissible to a reasonable extent and is made possible by making the packing rings "floating." It is necessary to make the bushing split so that packing may be accessible and rings or bushing may be repaired or renewed. Rings and bushings usually are made of cast iron or bronze. The friction loss in correct metallic packing is small.

Soft packing, so called, is made of various materials, cotton wicking, woven flax, rubber and cotton, asbestos, braided or wrapped metal thread or metal ribbon and other forms have all been used with success, depending upon the conditions of service.

The life of all soft packing is in general shorter than hard metallic packing, but its smaller initial cost is in its favor. If rod is shouldered, scored, out of round, bent, or eccentric to the stuffing-box, and especially if its eccentricity changes along its length, the packing will wear and frequent setting up and consequently occasional renewals will be necessary. It is rather common practice to put in new rings of soft packing above the old. It is well occasionally to pull out all the packing and examine its flexibility and especially the condition of the inside surface. The rings may be so hard that they are almost like solid metal and the hole in them may be larger than the rod—with the result that such rings merely fill up space, thus reducing the pliable surface in contact with the rod and making necessary a tighter setting up on the gland to prevent leaking.

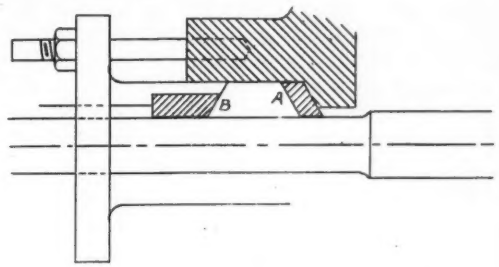


FIG. 3. SPLIT BUSHINGS TO RETAIN PACKING ON RE-TURNED PISTON ROD

When a rod becomes so badly scored that the packing cannot be kept tight without binding, it becomes necessary either to renew the rod or to turn a new surface upon the old rod. Since the strength of a rod decreases quite rapidly with any decrease in diameter, it is unwise to turn down a shaft without considering all the factors entering and perhaps consulting the manufacturers of the engine. A 2-in. rod turned to 1⅞ in. is reduced in area 12 per cent and its stress from the direct steam pressure on the piston is increased 13½ per cent. With long rods, the side deflection is important and largely determines their strength.

In case a piston rod is turned smaller the packing may give trouble by working between the gland or cylinder head and the rod. A good fit around the piston rod can be made by counterboring the gland and by inserting split bushings at A and B, Fig. 3.

Snap rings are commonly made of a thickness ⅛ in. greater than 1/30 of the diameter. The width is not as well standardized although ¾ in. is common for pistons up to 15 in. diameter and 1 in. for larger sizes. Width of ring is ordinarily made greater than thickness. The free diameter of ring is usually made ¼ in. greater

than bore of cylinder. Tightness of packing for both rods and pistons depends upon the fit between the two surfaces and not upon the pressure between them.

It is necessary that the groove be of uniform breadth and that the sides of the grooves be true planes. When fitting a ring into a groove one edge of ring should be made as true as possible, working to a surface plate if one is available and the scraping for fitting into groove confined to the other edge as far as possible. If pins are used, care should be taken to make them of a length to prevent the ring from working over them. If this

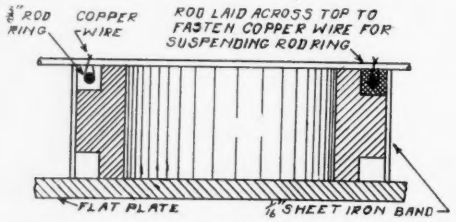


FIG. 4. BABBIT RING CAST AROUND PISTON

happens, rings are likely to be broken. Some engineers recommend that the corners of the ring be slightly rounded so that the ring will slide upon the film of oil on the surface of the cylinder instead of scraping off the oil.

It is important that piston rings have a proper fit sideways—easy but not too loose. They should be slipped into the cylinder to make sure that they fit and that there is enough opening between the ends to allow for expansion which should vary from 1/16 in. in a 12-in. bore to about 3/16 in. in a 30-in. bore. It is further suggested that the rings be heated to reduce the liability of breaking by laying them in boiling water before springing them over the piston. If it is neces-

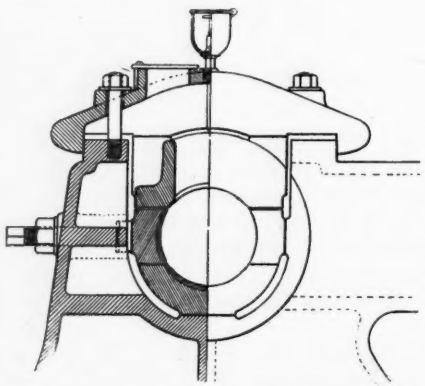


FIG. 5. MAIN BEARING SHOWING SECTIONS OF BOX

sary to pass a ring over a groove, slip 3 or 4 strips of sheet iron under the ring to prevent it from catching.

If a ring should break and have to be removed, an engine can ordinarily be run for a time with only one piston ring. Broken ring should be replaced as soon as practicable.

Temporary replacement of packing rings has sometimes been made by cast babbit. In one case, this was done as illustrated in Fig. 4 in which the babbit was cast around the bull ring of the steam piston of a pump. A sheet iron band formed the outside of the mold and the rings were reinforced by a 3/8-in. iron rod suspended as shown. These rings were dressed with file and scraper—no lathe was available—and served well until new rings were received.

Adjustment of Bearings

It often requires patience to locate a knock, especially when it is not very sharp. Flood bearings in the vicinity of the sound one at a time and notice carefully any softening of the pound due to the cushioning effect of the oil. A slack bearing can seldom be located by feeling, especially in the case of high speed engines, and incorrect location may lead to costly blunders.

Before overhauling a slack bearing, try the bolts, which may have just enough slack in them to cause the pound. If this is not the case it will be necessary to readjust the bearing. In a main bearing with quarter boxes, great care must be used in adjusting the wedges and quarter-box screws. Wedges and quarter-box screws have been set up when the bearing was cold and not given attention as the bearing warmed up, resulting in hot bearings and damaged journals.

It is well to adjust periodically the bottom and top shells of such boxes as well as the quarter boxes and thus keep each part of the bearing doing its full share. Wedges and shims should at all times have bearing of full area.

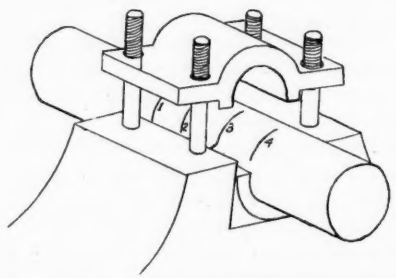


FIG. 6. LOCATION OF LEAD WIRES ON JOURNAL

Before taking any bearing apart for refitting, present setting should be distinctly marked. If bolt nuts are marked, record should be made of their setting.

Avoid making crude personal marks on engine parts; a fine scribed line will fully serve a careful workman. In slacking off turn each nut a little in turn, using as much care in slacking off as in setting up. When the cap is removed, wipe oil from all parts and caliper the shims.

A good way to ascertain the fit of the cap is by the use of soft lead wiring. These are placed around the upper half of the journal as shown in Fig. 6. Usually three or four will serve. The cap is put on and pulled down square until a solid bearing is felt. The new position of the nuts is scribed, the cap removed, and the thickness of the leads measured by micrometer. The leads generally leave an outline on the metal and if the thicknesses are marked with lead pencil at the proper points of the surface, the scraping can be done to these measurements. It may be necessary to go through this process more than once. It is usually not practicable to lead the lower half of the bearing, and if it needs refitting it is best to remove it if possible and scrape it to fit the shaft or a mandrel (Fig. 7). In spotting,

prussian blue, lamp black, or red lead coated thinly on the journal serves to show the high spots. The oil grooves should be deep enough to provide a good reservoir for oil; cut them deeper if necessary. Do not leave a sharp edge at sides of the groove.

Watch the bearing closely after putting into operation. If it heats quickly adjustment is not correct. If it heats slowly so that after a few hours' running it is just a little uncomfortable to the hand, it is safe. In feeling of a bearing the temperature of the surroundings must be considered; crossheads operate at a higher temperature than other parts on account of the heat from the piston rod.

Babbiting

Always select a high grade babbit with a known reputation. The old babbit is best removed by means of a blow or gas torch with bearing over a sheet of iron for collecting the metal. If the babbit was loose put in additional anchor holes. Shell must be clean and dry.

Clean the melting crucible and ladles by sprinkling liberally with powdered resin and burning it off in the forge fire.

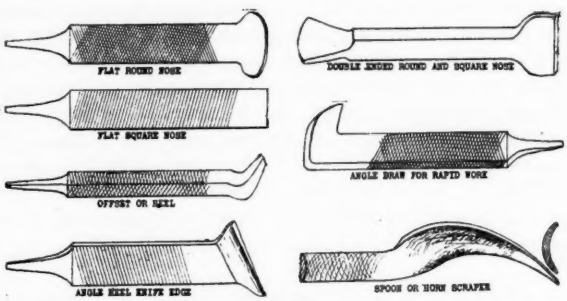

FLAT ROUND NOSE
DOUBLE ENDED ROUND AND SQUARE NOSE
FLAT SQUARE NOSE
ANGLE DRAW FOR RAPID WORK
OFFSET OR SKEL
ANGLE SKEL KNIFE EDGE
SPOON OR HORN SCRAPER

FIG. 7. FORMS OF SCRAPERS FOR BEARINGS MADE MOSTLY FROM OLD FILES

When lining a bearing, it is best to cast on a mandrel about an inch smaller than the shaft journal and then to peen the lined metal into the shell in order to make it more dense and make it fit tighter, since the babbit shrinks when cooling. It is well when possible to heat the shell and mandrel before pouring in order to reduce chilling, to insure rapid flow of the babbit and obtain a snug fit in the shell. In most cases this can be done conveniently with a torch. In the case of a crankpin it was suggested to heat a piece of metal that will easily slip over the pin and leave it there while doing other necessary work.

Sometimes the babbit is poured around the shaft and when this is done it is advisable to wrap one thickness of stout brown paper around it, which prevents the babbit from pinching the shaft and reduces somewhat the chilling effect of the shaft on the babbit. Bearings should be cast on end when possible. Figure 8 illustrates a main bearing cap set ready for pouring. Good banking materials are, among others, glazier's putty and fire clay mixed with asbestos. Always allow space for extra metal at top to take care of shrinkage. When bearing is cast in place liners must be provided to separate the halves and to give allowance for wear take-up. Generous V notches must be made to permit free flowing of the metal into the lower half. Although oil grooves can be cast in, better results can be obtained by cutting them by hand.

Melt the metal near the work as possible and melt sufficient to complete the casting in one pour. The metal is ready to pour when a light pine stick held in the molten metal smokes or chars and transmits a vibration or trembly feeling to the hand. It must not be too hot when poured. A small piece of resin stirred into the metal makes it run better. Pour carefully, slowly at first to make sure that clamping is tight and then in a

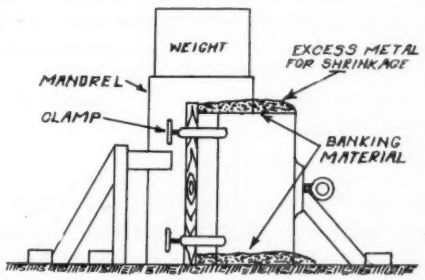


FIG. 8. MAIN BEARING CAP SET READY FOR POURING

fast steady stream until excess reservoir is filled. With a large bearing two ladles should be used so as to keep a continuous stream, and it pays to puddle or pump the metal in the mold with an iron rod while pouring.

Cooling quickly makes the metal lining denser and more durable. This can be done by means of a blast of cold air or by carefully pouring water upon the bottom of the bearing shell but do not let the water come in contact with the molten metal.

A crosshead shoe can be babbited successfully as follows: Measure diameter of bore of guides and get a hardwood block 4 in. thick, 3 in. longer and 1 in. wider than shoe with one end squared. Turn in a lathe to diameter of the guides and trim to exact width of shoe. Cut away the old babbit on each corner so that ends of stop screws S, Fig. 9, may come against casting. Next nail strips of wood to one end and two sides of the

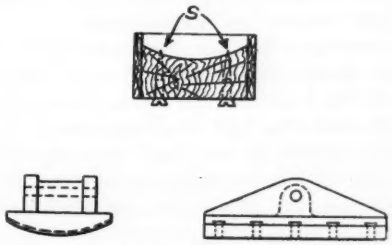


FIG. 9. WOODEN MOLD FOR BABBITING CROSSHEAD

wooden block. Cut out all old babbit, give inside of form a good coat of laundry soap, clamp wooden shoe upon casting and pour the metal. This will give a nice clean casting without dirt or blow holes, ready for service after filing the corners round and cutting oil grooves. It is not likely that the job could be done as quickly in the lathe, since this would necessitate removing the crosshead and making a mandrel. The whole job should not require more than 8 hr. from the time of stopping to time of starting the engine.

Always be sure that enough anchor holes are provided to hold the new babbit. Anchor holes should be ¼ in. to ⅜ in. in small bearings and up to ¾ in. in large bearings and should be slightly countersunk to prevent breaking off due to sharp corners. Holes must be at angles with each other and it is a good plan to drill "root holes" of a smaller diameter at an angle to the anchor holes. Before pouring the babbit, plug up the oil holes with wooden pins.

It is dangerous to pour babbit into a wet mold since steam is formed which sometimes acts with explosive violence and discharges the metal from the mold which may cause burns, or grave injury to the eyes. If moisture is suspected pour slowly with face turned away using long handled ladle, if possible. The danger is greater if the mold is small and deep such as would be the case in anchored bolts.

Compression

Compression serves two excellent purposes, first to stop the reciprocating parts at the end of the stroke, and second to raise the steam pressure and with it the temperature of the steam remaining in the cylinder to an amount more nearly equal that of the entering steam than is the temperature of the exhaust.

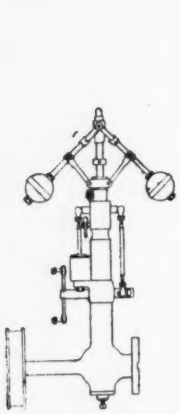


FIG. 10. BALL OR GRAVITY GOVERNOR

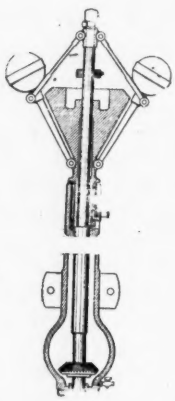


FIG. 11. WEIGHTED BALL GOVERNOR

The customary amount of compression is about 4 per cent for engines running 50 to 75 r.p.m. under moderate pressures, 8 to 9 per cent for 150 to 175 r.p.m. and higher pressures, while for high speed engines it will run from about ⅓ to about ⅔ and may cover nearly this range in the same cylinder of single-valve automatic engine in which the amount of compression diminishes with the lengthening of the cutoff.

The uniflow engine has a long period of compression which endures from the instant the exhaust port is closed by the return stroke of the piston to the end of the stroke. Compression may be equalized between the two ends by adjusting the length of piston rod or the length of connecting rod which increases compression at one end and decreases it at the other.

By stopping the reciprocating parts compression maintains the pressure on the same side of the bearings through practically the entire length of the stroke and prevents knocks and wear due to reversal of the pressure at high velocity. Although it is commonly stated that it is best to raise the pressure due to compression to one-half the admission pressure the compression pressures met in successful operation vary much both above and below this value. In a given engine the compression is ordinarily adjusted by changing the setting of the exhaust valve to close earlier when greater compression is desired and to close later to reduce compression. With the D valve driven by fixed eccentric this is easily done by changing the inside lap, lengthening it to increase and shortening it to decrease the amount of compression. Such changes alter release also, making it later when increasing the inside lap and earlier when decreasing this lap. With a Corliss engine compression may be advanced (made higher) and the release retarded by shortening the radial links on the exhaust. In the case of the single valve automatic engine the compression changes widely with the position of the valve and any change in the inside lap is usually inadvisable. Lap should not be removed until all adjustments have proved futile. Lap once removed cannot easily be put on again.

If compression is unequal at the two ends it may be equalized by changing the length of the piston rod or connecting rod. In general the piston should be moved toward that end in which a higher compression is desired, in which case the compression at the other end will be decreased. This will bring about a slight change in position of each cutoff which would ordinarily be neglected but which could be easily corrected in any form of four-valve engine. Occasionally it has been found advisable to reduce the clearance volume and thus increase compression at one end only by attaching a round flat plate to the cylinder (or piston). Before doing this, it is advisable to make sure by careful preliminary measurements that there is sufficient room for the plate, and that no screws or nuts will strike.

Equalizing Loads Between Ends of Cylinder

When everything is considered the most satisfactory running exists when cards taken from the two ends of the cylinder under steady load or blocked governor are as nearly alike as possible. There are seldom good reasons for deliberately departing from this adjustment unless one wishes to make a correction for the difference in piston area in the two ends of the cylinder. As an instance, a 10-in. piston with 2½-in. piston-rod has 78.5 sq. in. and 73.6 sq. in. areas. With cards of exactly equal area the two ends would deliver power in direct proportion to these two numbers.

If we wish equal work from the two ends, the area of the crank end card must equal 78.5 ÷ 73.6 or 1.065 × the area of the head end card. With unvarying compression and release at the two ends this correction would be made by adjustment of the cutoff, making it later on the crank end. With the single D valve or automatic single-valve engine a reasonable amount of adjustment to this end can be made by shifting the valve on the rod or changing the length of the eccentric rod—away from the crank shaft if it is desired to increase the work of the crank end.

A similar change may be made with a two-valve (riding valve) arrangement with fixed length of outer valve by shifting the outer valve. It is to be borne in mind that the changes suggested for the automatic and D valves affect admission (lead) as well as cutoff and

that for this reason the amount of such changes is rather definitely limited.

Equalizing Load Between Cylinders

In a compound engine, it sometimes is desired to change the proportion of loads on the cylinders. The load may be satisfactorily distributed for a certain average load, or steam pressure, or low-pressure exhaust and be far from satisfactory when one or more of these conditions is materially changed. In order to throw more work on the low-pressure decrease the low-pressure cutoff. This will increase the back pressure of the high-pressure cylinder, decreasing the work performed by it and increase the admission pressure of the low-pressure cylinder, which will perform a greater share of the work owing to the higher admission pressure and in spite of the earlier cutoff.

In cross-compound engines as ordinarily coupled with cranks set at 90 deg. it is highly desirable that high-pressure and low-pressure cylinders perform equal work and that in each cylinder the load be equally divided between head and crank ends, since this supplies quite uniform driving torque with resulting good uniformity in rotative velocity, which calls for a lighter flywheel for a given service than does a single cylinder or tandem compound engine of the same power. In the case of the single tandem compound, since the two cylinders drive the same crank this consideration does not enter, but here, too, it is advisable to have the load reasonably well distributed since otherwise valves are likely to be noisy and temperature conditions in the cylinders may be unfavorable to economy in steam consumption.

Speed Changes

When one has a ball or weighted governor which operates satisfactorily and desires to change the speed of the engine it is a good plan if possible to change the driving mechanism of the governor so that it will continue to rotate at the former speed under the new speed of the engine.

Adjustment for small changes in speed depends upon the type of governor—if on a Corliss engine, in which case the governor controls the position of cutoff and admission only, the length of the link on the governor post connecting the collar with the rocker may be adjusted to give cutoff for a lower position of the governor balls when decrease of the engine speed is desired, and to give cutoff for a higher position of the governor balls for increase of engine speed. See Figs. 10 and 11.

In case of throttle control with spring resistance, change of speed is secured by changing the tension of the spring or by altering the length of the spindle to the poppet valve. It is important to keep in mind that small balls at high speed with spring or weight loads give a sensitive governor and that heavy balls give power.

Racing and Adjustment of Governors

A stiff governor will add to the tendency to racing. Every bearing on governor and valve gear should be so adjusted that the rod can be freely moved sideways on the pin and with weights and balls removed and the valve links disconnected it should be possible to move the mechanism up and down freely through its entire range of motion. The oil in the gag pot should be kept at the proper level by adding a little occasionally to make up for evaporation.

The power of a given governor may be increased by increasing its speed and this may sometimes be advisable. It may be done by decreasing the diameter of the pulley on the governor and adding weight to the governor to bring the engine up to the normal speed. After the correct amount of weight has been determined by trial, a weight of suitable size and shape should be made and securely attached to the governor. For weighted governor see Fig. 11.

Shaft governors which control the valve of a single valve automatic engine must be powerful as well as sensitive and most governors of this type make use of the inertia as well as the centrifugal effect of a comparatively heavy weight.

Inertia type shaft governors can be adjusted to control the speed within a range of less than one per cent between light load and full load. They must have zero load or blanked steam ports when governor is in the outer position, since if there were lead at this position the engine might run away under no load.

In the running position, which is generally that which gives ¼ to ⅜ cutoff, the valve must have sufficient lead to give proper running and a good steam line. Unfortunately, with most governors the lead continues to increase with the increase of cutoff and may become excessive when the governor is in its inmost position. This condition is not seriously objectionable, since it insures the highest possible steam pressure up to cutoff and hence holds up the capacity of the engine.

When it becomes necessary to adjust a shaft governor, no time should be wasted in experimenting with the governor until its effect on the speed of the engine is known. If the engine is working well enough to allow time for observations, watch the voltmeter and ammeter. An increase in amperage with a permanent decrease in voltage, and vice versa, indicates that the governor is not sensitive enough—that it requires too great change in speed to govern.

A momentary increase in voltage with return to normal caused by a decrease in load is to be expected and is all right when confined within narrow limits.

An increase in load with marked rise in voltage which drops back after 2 or 3 sec. indicates that the governor swings too far before it controls the engine. This particular condition is usually accompanied by "hunting" in which the engine runs now fast and now slow upon the least disturbance of the load. An opposite condition in which the engine drops off in speed upon increase of load and recovers slowly, and vice versa, shows that the governor, though sluggish in action, is accurate enough in regard to speed.

Quicker and equally satisfactory results can often be obtained by taking the engine out of service and loading it with a simple plank brake operated by 1 or 2 men with which the load can be changed instantly.

The following suggestions which apply directly to the Rites type of governor are applicable in many particulars to most of the shaft governors in common use.

1. It is well in starting to examine the condition of the main governor pin and other pins and repair them if necessary. Bush them if they are too loose.

2. Adjust the governor spring to bring the speed right at ¼ load.

3. Load to full and note the drop in speed. If it is greater than 1 to 1.5 per cent the spring is too stiff. Remove any weights from the short end of the governor arm and slacken the spring until speed at ¼ is correct and again compare with speed at full load. It may do better to add weight to the long arm instead of taking weight from the short arm.

4. It may be necessary to look for a hard pulling steam valve—pressure plate may be fitted too close, or valve may be cutting, or packing of stem may be too tight.

5. Run at full steam pressure under no load. Valve should move practically the length of its lap allowing just enough steam to enter to overcome the friction of the engine. It may give a little lead or the valve may leak or lap may be too short, with the result that the engine may run away at no load. It is best not to limit too closely the speed under no load; no harm can result if the engine runs several revolutions faster under no load than under a light working load.

6. Observe the steadiness of speed under a change of load. If the speed makes several swings above and below normal before becoming steady, or if the governor is too slow in bringing the speed to normal after a change of load, weight should be added to the long end.

7. The falling of the governor weights due to gravity, especially in the larger engines, sometimes causes most unaccountable speed variations, which can usually be corrected by a friction brake against the governor arm.

8. When a shaft governor hammers on the stops on shutting down it can generally be stopped or reduced so that it is harmless by adding a small weight on the spring side of the governor arm and increasing the tension of the spring correspondingly.

9. If three or four changes have been made and the action still is not satisfactory, make sure that none of the changes operate so as to cancel or partially offset each other. Careful choosing of the method to bring a desired result will save much time by preventing false moves. If a weight is to be added to one end of the governor arm, it may serve the same purpose to remove a weight from the other end.

Speed Stops

The most important thing in connection with speed stops is dependability and it is necessary that they be kept clean and lubricated and that they be tested frequently—once every week is none too often. This can be done conveniently at the time of shutting down. The engine should be stopped by means of the emergency stop by throwing it in now at one operating point and now at another. When conditions permit it is well to make an occasional test by holding down the governor (or blocking it in the case of a shaft governor) and letting the engine speed up until the stop is thrown into action. When doing this, it adds greatly to the value of the trial to take the maximum speed of the shaft with the aid of a tachometer and thus check the adjustment of the device.

When engines are operated condensing, an automatic vacuum breaker is usually provided in addition to the engine stop.

Setting Valves

Valve setting may be done with reasonable accuracy and quickness by measurement, but it is better if possible to employ the indicator especially for the closer refinements. With a D valve engine, first get the right valve distance as follows: Move the eccentric to its extreme inward position and make a mark on the valve stem flush with the outer end of the gland, next turn the eccentric to its extreme outward position and mark the valve stem, next find the point halfway between these two and turn the eccentric until this middle point comes flush with the gland, fasten the eccentric temporarily and adjust the valve on the valve stem to lap the two ports equally. Next place the engine on dead center, loosen the eccentric, set for lead, and fasten it. The check for correct setting is in the lead which should be equal or nearly equal at the two ends. If the two leads are greatly unequal correct half the error by moving the valve on the stem and the other half by rotating the eccentric.

In setting an automatic cutoff valve, the procedure is the same excepting that it is well to block the governor at the position of ordinary running, say about ¼ cutoff. Since the valve which is to be set is ordinarily somewhat out of adjustment, the position of the governor can only be gotten by trial, or it may be better to set the valve with the governor against the inner stop and correct later from the indicator diagram.

To test a valve for leakage, block the engine securely and carefully open the indicator cocks in turn. To test the piston for leakage, block the engine and admit steam to one end with the indicator cock on the opposite end open.

Since the pressure on the indicator piston should correspond as nearly as possible in time and amount to the pressure in the cylinder of the engine, short free pipe connections are advisable, especially with high-speed engines. Long or small indicator pipes with contracted openings through fittings or cocks detract from the truth of the card. It is imperative that the correctness at head and crank ends be as nearly alike as possible in this respect, since comparison of the cards from the two ends is always valuable. Friction of the indicator resists the motion of the indicator pencil—cards are smaller and may lag a little behind the piston.

Lost motion may cause an increase of area or a decrease of area depending upon speed and friction conditions in the indicator motion and between pencil and card. Pencil may take highest position on the steam side and lowest position on the exhaust side and thus enlarge the card or it may act in the opposite manner and reduce the area of the card. Since the direction of this action is usually uncertain, lost motion is particularly objectionable.

A little lost motion in the reducing motion is usually not serious. Its effect is to lengthen the card, and may result in different length of cards at different speeds of engine. If used often, it should be put in good repair. Lost motion in a simple lever rig can be stopped sometimes by arranging a spring to hold the lever against one side of the pins. Whip of the cord distorts the card and since it can easily be stopped by providing a suitable guide ought not to be allowed to continue.

Knocks

Knocks in an engine are often hard to locate and it is usually done by a process of elimination. The method of flooding mentioned in connection with adjustment of bearings shows when the trouble is in the bearings but is of no direct service in other cases.

In one instance, a knock inside the cylinder was found to be due to a piston rod nut which in assembling had come up tight by binding on the thread instead of pinching the piston. This permitted the piston to strike at one stroke against the nut and at the other stroke against the shoulder on the piston rod. The trouble was easily removed by putting a thin washer under the nut.

A rather unusual case of knocking was caused by a piston ring running a short distance over the tapered end of the cylinder bore at one end of the stroke. Such a condition could be stopped by shifting the piston provided the clearance at the other end was large enough, or by widening the ring by an amount equal to the overrun and widening the groove in the piston on the proper side.

In another case, the lock nut on the piston rod at the crosshead had worked loose and owing to a loose fit of the threaded end of the piston in the crosshead a small knock resulted, which was easily removed by setting up the nut.

If the nut retaining the crosshead pin works loose, the pin may work out a small amount and knock at the tapered end. These instances illustrate the necessity for properly setting up nuts and locking them whenever possible.

Knocking may be due to unequal wear of the bearing of the connecting rod at the crosshead. Owing to the conditions of service the crosshead pin wears on the front and back and almost none on the top and bottom, so that when the brasses are set up close together there is an appreciable binding effect between pin and brasses as the connecting rod moves through the limits of its swing; e. g., for crank positions near the forward and return 90 deg. positions. This may be sufficient to make the crosshead slap the guides, as, for instance, in the forward stroke of an over-running engine by actually lifting the crosshead from the lower guide and making it strike the upper guide. This condition can be stopped by taking a light cut off the pin and fitting the brasses to it. Some engine builders flatten the top and bottom of their crankpins and thus remove, or greatly delay, this trouble.

If the shaft is out of line and the crosshead shoes are loose, this lack of alinement may cause a pounding of the crosshead by sidewise shifting in the guides. Knocking due to this cause may sometimes be stopped by correct adjustment of the crosshead; but if it is known to be due to the angularity of the shaft, the shaft should be squared at the first opportunity because this condition means eventual trouble with some of the bearings which may involve a lot of work.

End play in a Corliss valve will sometimes make a troublesome noise. In one instance, this was easily stopped by turning back the flange of the bonnet, in another case a pin was driven centrally into the bonnet and squared off to suitable length.

Knocks in crankpins due to end play can be stopped by lengthening the box or the babbit. This same thing may be done on crank shafts. If the shaft carries a rotor, the shifting of the rotor a small distance along the shaft will usually cure the trouble since the shifting will change the magnetic lines so that the shaft and rotor will not "float" but be definitely held to one side.

Vibration

Vibrations are due to two principal causes, the unbalance of the engine and the intermittent flow of the steam. These two causes may act together.

Vibrations through the foundation due to unbalance are usually absorbed in the foundation but may be transmitted through the soil especially if it be rock or wet soil. The remedy in either of these cases is to increase the weight and spread of the foundation or better to put an elastic pad between the engine and the foundation. Rubber, felt, cork, and in some cases wood have been used with success, cork being generally preferred. To give durability and effectiveness, it is usually found best to fit the cork into a metal frame.

Sometimes the vibrations are carried from the sides of the foundation horizontally into the walls of the buildings, this condition is sometimes much improved by removing the side filling entirely or by replacing it with loose sand or similar filling.

Vibrations in the piping may be removed by placing a receiver in the steam or exhaust line. Sometimes this is accomplished by the receiver at the cylinder as ordinarily connected or by the oil separator in the exhaust, especially if it be a large one. If the branch to the engine is long, it may be necessary to put the receiver at the outlet from the header and break up the flow by passing the steam through orifices or holes inside the receiver. A similar arrangement may sometimes be necessary in the exhaust especially if it connects with a heating system. Rigid anchoring and, on the other hand, elastic supporting have both been effective.

Water in Steam

Water in steam means loss and annoyance. Its effect on lubrication has been stated. Initial condensation always occurs to some extent with saturated steam and usually occurs when the amount of superheat is quite small, and it may run as high as 20 per cent under unfavorable circumstances. A certain part of this heat is recovered through re-evaporation. It is commonly stated that each 2 to 3 per cent of moisture in the cylinder represents 1 per cent of loss in heat.

The danger to life and to the engine resulting from the pocketing of water between the cylinder head and the moving piston without sufficient freedom to escape is well known. An ample separator properly drained will usually preclude accidents of this kind. Before starting, it is imperative to make sure that separator, piping and cylinder are drained free from all water.

Emergency Repairs

A few cases of emergency repairs are given by way of suggestion only. In one case, the low-pressure side of a cross-compound condensing engine gave out. By disconnecting the low-pressure connecting rod, and making a temporary pipe connection to the condenser from the high-pressure cylinder, it was possible to furnish well over one-half the power ordinarily required. It might be possible in an emergency like this to increase the steam pressure and thus get additional power.

A shouldered crankshaft broke squarely off as indicated in Fig. 12 and was replaced by a straight stock shaft, which was quickly procurable, on which a bushing was fitted.

The piston rod shown in Fig. 13 was repaired by squaring off the rod, tapping, and securing by means of a long cap screw. The babbit added stiffness to the job. Pistons seldom give out; but in some instances, cracked pistons have been fitted with shrink bands and in others have been replaced temporarily by pistons turned from available blocks of metal, sometimes only

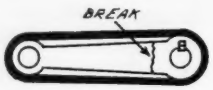


FIG. 12. EMERGENCY REPLACEMENT OF SHOULDERED SHAFT

thick enough to accommodate one ring. If it becomes necessary to heat a piston having closed core spaces, it is wise to remove the plugs or to drill holes to the cores since there may be enough moisture inside to cause an explosion. A broken rocker can be repaired by shrinking on a band as shown in Fig. 14. A breaking out of a pin could be repaired in a similar manner. In the case of extreme urgency, these repairs could be made by bolts and saddle pieces.

Some one of the modern methods of welding can often be used to advantage. When skillfully handled, such welding may sometimes be used for cylinders, cylinder heads, rods and pins; but they are far more readily appli-

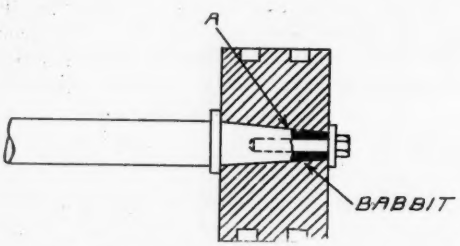


FIG. 13. TEMPORARY REPAIR OF PISTON-ROD

cable to frames, cranks, wheels and the like at points where considerations of wearing surfaces and alinement do not interfere.

Reboring

Reboring may be done in the machine shop whenever the construction of the engine and the provision for handling make this possible. On the other hand, reboring in place has the advantage that the engine need not be removed from its foundation or, in the case of a large engine, that it does not have to be dismembered in a manner requiring difficult re-installation.

Reboring should be done by a man skilled in this class of work. A cylinder may be seriously damaged or even ruined by using too light a rigging, or setting it up insecurely, or by careless feeding of the tool. In reboring a cylinder the depth of the cut should be kept at a minimum. It is often surprising how much a surface may be improved by cutting away 1/64 in. or even less.

Monthly Inspection

Once every month on a specified date (or oftener) an examination of the engine should be made to determine its running condition. Bearings, and all wearing surfaces, clearance of piston, condition of cylinder bore and rings, action of dash pots and governing mechanism are especially important in this connection. It is well to take indicator cards and speeds at such times, and a log book should be kept in which indicator cards may be mounted and record made of speed and other important items and notes made of repairs, adjustments and improvements requiring attention at the first opportunity.

Lining Up

Lining up is a simple matter in the high-speed engine, since the frame and the cylinder are machined so as to bring the cylinder and guides into line and the main bearings are machined at a right angle to the guides. In this case, the outboard bearing can be brought into line by clamping the shaft firmly into the main bearing and adjusting the outboard bearing so as to line up with the shaft.

Some large engine frames are somewhat out of line, due to the spring of the boring bar when cutting hard spots in the castings and as a result the cylinders may be out of line with the guide barrel. It is rather common, in modern engines, to counterbore at the ends of the guide surfaces and at the ends of the cylinders, thus giving points not subject to wear from which lining up may be done.

Remove the reciprocating parts and stretch a line through the entire engine and attach to adjustable supports as shown in Fig. 15. Use a fine silk or sea grass line, stretched so as to remove the sag. For the cylinder make a small tram of soft wood about the size of a lead pencil cut ½ in. shorter than the radius of the cylinder, and drive a small brad in at one end to make up the required length. Make a similar tram for the guides.

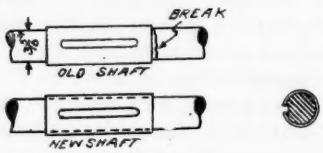


FIG. 14. REPAIR OF BROKEN LEVER BY SHRINKING ON STRAP

Now by tramming top and bottom and sideways, adjust the line so that it is central with the guides. Next test the cylinder by using the other tram but do not disturb the line. If the cylinder is not in line find the amount of the error by putting paper or other thickness gages under the tram.

If cylinder is not over 0.012 in. low at the back end it may be wedged into line, but the frame must not be thrown out of line by doing this. If the cylinder is out of line sideways, it will be necessary to back off the cylinder and file one of the surfaces. After fastening the parts together it is best to test again for alinement. If the engine has adjustable guides, it is best to set the stretched line to the cylinder and then to line up the guides with the cylinder, making due allowance for

the crosshead. This may necessitate shimming of the guide bars.

The shaft should next be leveled and squared. The shaft is generally brought to level by raising or lowering the outboard bearing. The makers usually provide means for this adjustment. The shaft is squared by adjusting the outboard bearing sideways so that when the crankpin is brought against the stretched line at the head and crank centers, the distance from the line to the end of the pin at the two positions is equal.

To line up the bearings when the shaft is not in place, stretch a line through the center of the main bearing (C-D Fig. 15) at right angles to the line through the cylinder and guides (A-B) and center the outboard bearing upon this line. The lines may be put at right angles in the following manner: Make a strip of wood 4 to 6 in. wide and 6 to 8 ft. long with ends pointed eccentrically as shown at F in Fig. 15 and mark the exact center with a sharp line. When this strip is placed with its long edge against the line A-B and with its marked center at the point where the lines A-B and C-D cross, any point, such as E on the line C-D, should be equidistant from the ends of the piece F. Point E must be taken 3 to 5 ft., say, from A-B. If these two distances are not equal, the position of C-D must be shifted until they are. In shifting C-D, care must be taken to keep it central with the main bearing.

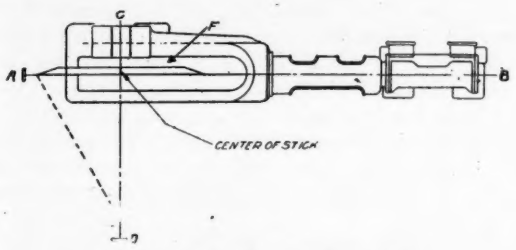


FIG. 15. SQUARING CRANKSHAFT

It is best to have the center line of the shaft in the same plane with the center line of the cylinder and guides; but, if the shaft is a small amount high or low, it will not affect successful operation.

Next put in piston and crosshead, center the piston by the junk ring if there be one, and adjust the crosshead shoe to the center of the piston rod. The connecting rod may now be connected to the wristpin, keyed up snug, and tested for correct alinement with the crank pin. Correct alinement exists when the brasses of the connecting rod meet the crankpin journal centrally without forcing.

An easy method of testing the alinement of the crankpin is to disconnect the connecting rod from the crosshead, tighten the brasses at the crankpin and note any motion of the crosshead end of the connecting-rod sideways from the center line of the cylinder as the crank is put at various angles. If the shaft is square and the crosshead end of the connecting-rod remains central sideways, the crankpin is in line. If the shaft is square and the connecting-rod shifts sideways from the center line, the crankpin is out of line.

A somewhat rough though quick and often sufficient method of squaring the crankshaft is to remove the cylinder head and place a straightedge horizontally against the end of the cylinder. If the cylinder and guides are in line with each other, and the rear flange on the cylinder is square with the bore the shaft should be parallel with the straightedge in order to be square with the cylinder.

Foundations

It is well to follow the advice of the engine builders in the matter of the size, depth and spread of the foundation, and all details of reinforcing and foundation bolts.

Oil should be kept away from the foundation since it softens concrete and mortar. In one instance where oil had done damage, the foundation was cut away to the depth of 3 or 4 in. at bearing surfaces, engine wedged up to level and the space filled with a mixture of sharp sand and Portland cement, one to one, with a small percentage of iron cement. Three coats of protective paint finished the job.

Anchor bolts should be sulphured or leaded after lining up the engine especially in the case of large units, to avoid as far as possible any danger of working loose.

Valve Setting on Large Engines

Methods of Setting Valves on Large Engines Without Turning Over Crank or Flywheels. By A. C. Waldron

SETTING ENGINE valves on engines of small sizes, when they can easily be turned from one center to the other and where there is little or no friction load to shafting and belts, is not an undesirable job. Where the engine is of such size, however, that it takes from one to a dozen men to bar her over, it is likely to be the cause of many neglected verifications of valve setting.

I am showing in the following, how the valve setting may be a one-man job on almost any drop cutoff engine, which otherwise might require a dozen men. This is not a new idea, but it is safe to say, many will be glad to know the principles. It may be applied regardless of where the engine may have stopped, whether the crank is on the center or whether it stands up at 90 deg. as in Fig. 1 or at 120 deg. Let the crank remain in any position it may come to rest until you are ready to start up again and for final indicator verification.

The usual methods of Corliss single eccentric valve setting will give an outline of the principles, although double eccentric engines can have the separate eccentrics set by the crank circle method as in the case of the single eccentric engine.

We will assume that the hook rod and eccentric rod are the correct length and that because plumb lines dropped down the center of the wristplate and rocker arm shown is equal on each side. Shorten the dashpot rods so that when hooked up and the eccentric is turned around on the shaft they will not bottom and jam. Now put the governor on the safety pin, set the wristplate central, hook on both steam valves, adjust valve rods until both steam valves show 1/8-in. lap for an 8 to 10-in. cylinder and 1/2 in. for a 30-in. cylinder for ordinary work, and adjust exhaust valve rods so that the exhaust edges will be line and line.

Now, in order to get the dashpot rod the proper length, roll the eccentric around on the shaft and see that when the eccentric is at either extreme, the hooks will have 1/16 in. clearance on the block and will be

sure to pick up the valve. Next put the governor in its highest position and with a starting bar rock the wrist-plate from one extreme mark on the hub to the other. The governor reach rods should be adjusted so that steam valves should not pick up or, if they do, not enough to uncover steam lap, which would admit steam while engine was racing. Next take out safety pin and drop the governor to its lowest position; adjust safeties so that they will bear against the crab claw, preventing the valve from being picked up, which may happen in the case of a broken governor belt.

In the first case, being a single eccentric Corliss the foregoing principles can be followed up to setting the eccentric so that it will be in correct position in relation to the position of the crank, no matter where it chanced to stop, and the engine will be ready to carry its load if the work has been done correctly.

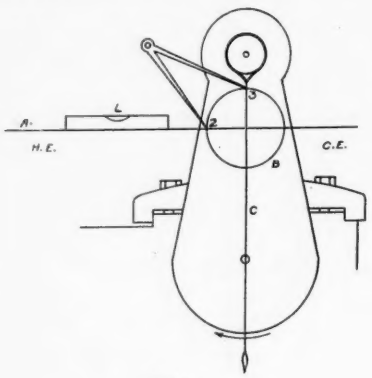


FIG. 1

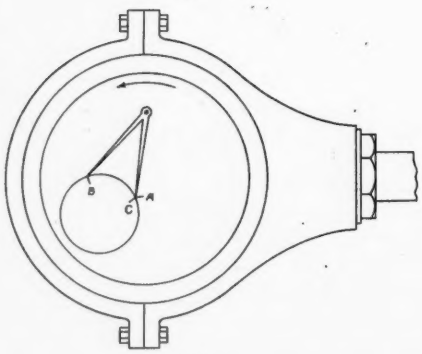


FIG. 2

FIG. 1. METHOD OF MARKING THE CRANK
FIG. 2. SHOWING LOCATION OF MARKS ON THE ECCENTRIC

Suppose the crank has stopped as shown in Fig. 1. Take a fine wire or thread, C, and make a loop around the crankpin; pull it taut so it will extend by the lathe hole in the center of the main shaft. Mark this line on the crank shaft at C, then caliper the main shaft near the eccentric and draw its circle anywhere on the face of the crank B, holding its center on the line C. Now, by means of a level, draw line A across the center of the shaft circle B. With the valve gear squared as described above, it now becomes necessary to place the eccentric; so advance the eccentric in the direction the engine is to run, say on the head end, until the steam valve on the head end just shows 1/16 in. lead. Now, go around to the eccentric and make a mark on the shaft and another on the eccentric opposite each other at A and C, Fig. 2, then return to the crank and take the distance on the shaft circle B, which will be from 2 to 3, as shown in Fig. 1. With the dividers so set, carry them around to the eccentric, Fig. 2. Place one leg at C on the shaft and the other at B, making a mark also on the shaft. Advance eccentric mark A from C to B. The eccentric will now be in its proper place to operate the engine and yet the crank or flywheel has not been moved while the work was done.

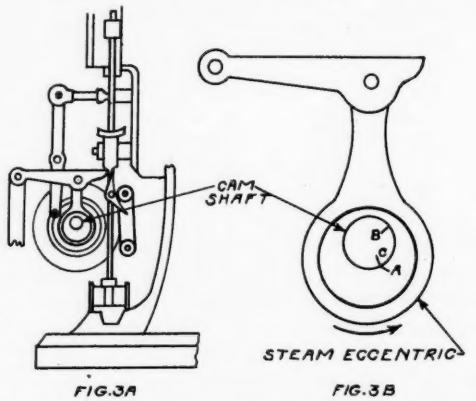


FIG. 3A FIG. 3B

FIG. 3. STEAM ECCENTRIC AND VALVE GEAR ON BROWN ENGINE

The case of a simple slide valve is practically the same. After squaring the slide valve, advance the eccentric for lead, then to place the eccentric follow the above marks and circle on crank and eccentric as described in the Corliss.

In case the engine is a Brown, Green, Putnam or Rollins or other make, methods of procedure differ slightly in adjustment, but the valves may be set without moving crank or eccentric. If it chances to be a Brown, after squaring the valves according to catalog rules, there will be four parts to move (two steam eccentrics and two exhaust cams) and the marks may be made on camshaft and eccentric cams as shown in Fig. 1.

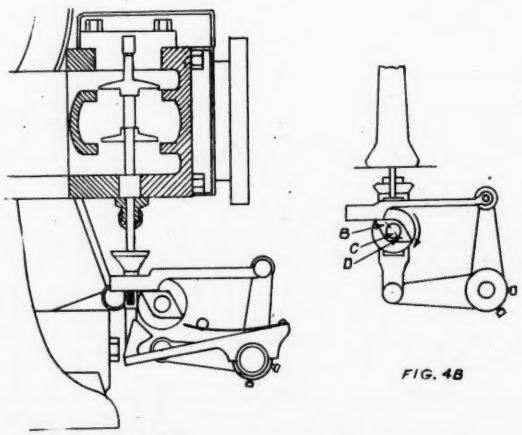


FIG. 4A FIG. 4B

FIG. 4. DETAILS OF PUTNAM VALVE GEAR

Figure 3B is an enlarged drawing of the steam eccentric shown in Fig. 3A. The mark on the eccentric (after giving the steam valves lead and exhaust valves slight compression) is to be advanced from C to B on the

camshaft, depending more or less on what the position of the crank calls for as designated by dividers shown at 2 and 3 in Fig. 1. The exhaust cams must, of course, be moved the same amount as the steam cams on the cam shaft. The circle in this engine is of course made from the camshaft near the valve gear and not the main crankshaft circle. In regard to the Putnam engine, the principle is the same except that the steam and exhaust cams must be moved one-half the circle distance 2 and 3, Fig. 1. This circle is also made the diameter of the camshaft. This is necessary because the camshaft in the Putnam engine turns but once for every two revolutions of the crankshaft, hence if the full distance 2 and 3, Fig. 1, was used, it will be readily reasoned out that it would be double the necessary distance, this case being different from the Brown camshaft, which turns one complete revolution for one complete revolution of the flywheel shaft and crank.

An enlargement of Fig. 4A is shown at Fig. 4B. The D mark on cams is advanced from C to B on shaft if called for in camshaft circle B, Fig. 1, but this distance must be one-half that shown on crank circle; remember, also, that in the Putnam and Brown engines this crank circle is taken from the camshaft diameter (near the valve gear) and not the diameter of the main crank shaft as in the case of the Corliss or slide valve and others. Of course, the double eccentric Corliss, as regards the preliminary setting of the valve gear for long range cutoff engines, is to be according to the rules until it comes to the placing of the steam eccentric. In this case, after the lead is given, the distance to advance the eccentric is started from this "lead point." In the case of the separate exhaust eccentric, after the wristplate is central with exhaust edges line and line (if so desired) the exhaust eccentric is advanced in the way the engine is to run, until the exhaust valve on the end taking steam closes to start compression. The amount the exhaust eccentric is to be advanced is started from this point. It must be remembered that conditions differ according as to whether the hook rod is attached to the exhaust wristplate above or below the center wristplate, also as to how the exhaust rods are attached to bell cranks which vary in different makes.

In case the crank should stop, say, beyond 90 deg. from head end or, say, 150 deg., it is difficult to use the dividers unless short spaces are stepped off and added together. Much better results can be had by laying a steel tape around the curvature of the shaft from 2 to 3 in Fig. 1, which gives more accurate results.

It is taken for granted that the reader will apply the indicator at the completion of the work to see if cutoff, compression and lead are suitable. If you will try this method of setting eccentric, however, on even a slide valve engine, you will be convinced of its value as a one man method of setting any size of engine.

I decided not to go into detail in regard to complete setting of the Brown and Putnam engines because I thought, as has been mentioned at the beginning of this article, that any progressive engineer will readily be able to apply the methods to these engines from what principles I have already mentioned. It must be remembered that if in the final indicating it is found necessary to make some adjustments to the cutoff, care must be exercised that the safeties are not misplaced so as to endanger the engine in case of emergency.

Condensers

Suggestions of Value in Maintaining the Condensing Apparatus in a High State of Efficiency

SINCE a variation of an inch in vacuum at the exhaust end of modern steam turbines may cause a difference of a pound or more in the water rate, it can be readily appreciated that it is of considerable importance to maintain the condensing equipment in its best possible condition. Economy in condenser operation consists in maintaining the desired vacuum with the smallest amount of water. Because of this fact, the condenser should be kept clean and free from scale. Scale on condenser tubes lowers the heat transmission and as a result a greater quantity of water is needed to condense a certain amount of steam.

The condenser and associated piping must be inspected frequently and overhauled if necessary. Pipe joints must be examined for tightness and stuffing boxes on the air and circulating pumps should be carefully gone over for the same reason. A vacuum pump, no matter how efficient, cannot maintain high vacuum if the engineer is careless about leaky joints. Two places often overlooked when inspecting for air leaks are the low-pressure cylinder valve and piston-rod stuffing boxes of compound engines. The pressure around these boxes, it must be remembered, is towards the inside, not towards the outside, and air often leaks into the system at these points in considerable amounts. The amount of work done by the air pump in handling the air in solution is small in comparison to the work it generally does in handling air which enters the system through leakage. The latter is often from 10 to 25 times as much as that ordinarily dissolved in water.

The most frequent form of leakage in surface condensers is at the glands at the tube ends. Much trouble due to corrosion due to chemical and electrolytic action is experienced at these points and leaks inevitably result. Some success has been obtained in preventing trouble of

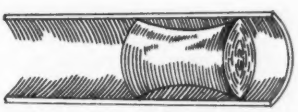


FIG. 1. SKETCH SHOWING THE USE OF RUBBER SLUGS IN CLEANING TUBES

this kind by spraying the tube ends with a black insulating varnish. Sometimes tubes are cut due to the direct action of the steam impinging upon them. This may be prevented by the installation of suitable baffle plates. Tubes exposed to the action of salt water, at times become brittle and crack.

The formation of scale upon the tubes is a condition which seriously impairs the heat transmission and must not be overlooked during inspection. If much scale or

mud is found to be present, steps should be taken to have it removed immediately.

The steam space should be inspected for grease and sludge which comes over with the exhaust steam and which accumulates on the tubes and shell. Such sludge is best removed by filling the steam space with a strong solution of soda ash and boiling out with steam. In doing this, suitable vents must of course, be provided so as to prevent the building up of pressure.

All gages and thermometers associated with the condensing equipment should be inspected and tested frequently so that there will be no possibility of their giving false indications.

Washing Tubes

Condenser tubes should be washed out frequently. In locations where river water is used as circulating

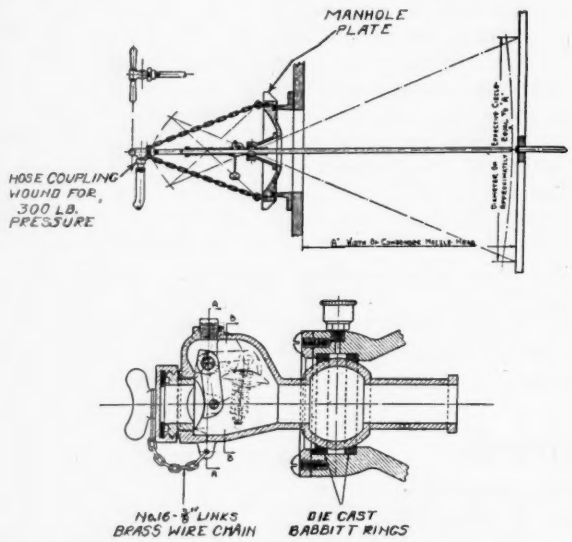


FIG. 2. DEVICE FOR CLEANING CONDENSER TUBES WHILE CONDENSER IS IN OPERATION

water the tubes should be washed at least once every two weeks. It does not take long under ordinary conditions for the tubes to become so coated with scum and slime that the heat transmission is seriously impaired.

The procedure to be followed in cleaning tubes depends upon the nature of the deposit. Mud may be washed out by high pressure streams of water. Brushes attached to long rods which may be inserted into the tubes and operated by hand are effective, but the process is slow.

The use of rubber plugs is well adapted to the cleaning of tubes when the deposit is of a slimy nature. One type of slug that has proved successful is illustrated in Fig. 1. These are placed one in the end of each tube and then blown through by compressed air or water under about 100 lb. pressure. The slugs fit tightly into the tubes and should be made of comparatively soft rubber.

In some large installations where the expense due to removal of a condenser from service for washing purposes is an important item, a method has been devised whereby the tubes may be cleaned while the condenser is in operation.

The apparatus which is shown diagrammatically in Fig. 2 consists of ball nozzles fitted into sockets attached to the condenser water boxes. In condensers designed to accommodate this equipment, these will be spaced about 36 in. apart and at a distance of about 36 in. from the tube sheet. The nozzle consists of a brass casting bored to receive a 1-in. steel tube lance, and is fitted at the outer end with a screwed cap for use when the nozzle is not in service. The lance which is inserted through the ball nozzle is held by four chains which prevent the lance from being blown back by the force of the water. A water pressure of 250 lb. or more is required for properly cleaning a condenser, the operation consisting merely of swinging the lance about so that the water strikes all the tube sheet and tube ends within its range.

Removing Scale

That the presence of scale in condenser tubes is a serious cause of condenser trouble is clearly indicated by the curve, Fig. 3, which shows the decrease in heat transmission due to the accumulation of scale in the tubes. It is evident that unless this scale is removed at frequent intervals, operation of the condenser would soon cease entirely.

Within recent years, the objections which many engineers had to feeding chemicals into condensers for the purpose of removing scale have been largely overcome. The chemicals used depend upon the nature of the deposits. Caustic soda is best for deposits of grease or mud. A 1 per cent solution (1 lb. caustic to each 100 lb. or 10 gal. of water) should be used at first and then gradually increasing to a maximum of 7 per cent. For scales composed mostly of sulphate or carbonate of lime or

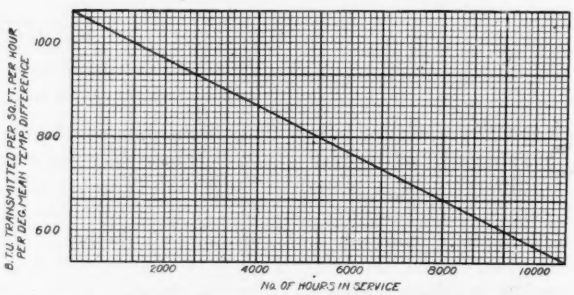


FIG. 3. CURVE SHOWING THE EFFECT OF SCALE IN CONDENSER TUBES

magnesia, a dilute solution of hydrochloric acid is most suitable. A 5 per cent solution may be used at first and the strength increased in severe cases to a maximum of 40 per cent. In using these solutions, close off the inlet and discharge valves to the water space of the condenser and provide ample vents on both ends so as to allow the gases to pass off and also to prevent the accumulation of pressure. A steam connection should be provided at the bottom. Allow the chemicals to run in slowly from a barrel above until the condenser is full and then turn on steam enough to cause the solution to boil slowly. In this manner, a condenser can be cleaned in from 6 to 8 hr.

Scale can also be removed by mechanical tube cleaners, in a manner similar to that used in cleaning boiler tubes. This is a method that is widely used and one that seems to give much satisfaction.

Another method is by the use of sand blast. A type of sand blasting nozzle that will enable an operator to clean from 100 to 200 tubes an hour is shown in Fig. 4. In operating this apparatus, the water supply is cut down to a very fine stream, the nozzle inserted in the end of the condenser tube, and after a quart of clean, dry, sharp sand is poured into the hopper, the air cock is opened full. About 20 sec. are required for driving a quart of sand through the tube.

Packing Tubes

There are several different ways in which the tubes of surface condensers can be secured to the tube sheet. The most common method, is by holding the tube in place by means of a brass ferrule which is screwed into a counterbore in the tube sheet. Each tube is packed with suitable packing material inserted around the tube at the bottom of the counterbore and the ferrule screwed down upon it. The method is clearly illustrated in Fig. 5, in which A is the ferrule, B the packing, C the tube sheet and D the condenser tube. Where this method is employed, the tube sheets must be carefully machined, so that the packing holes will all be of uniform depth and diameter and the tube holes in the sheet must be close to the tube size. The ferrules should all be drawn up to an even depth so that they will project an equal distance from the tube sheet, which will in turn insure uniform pressure on all the packing.

Various materials are used for packing, among which may be enumerated corset lacing or cotton tape, fiber washers and certain forms of metallic packing. Corset lace and wicking seem to be the most common. It is Navy practice to use corset lacing soaked in paraffin, tallow, mineral oil or boiled linseed oil and then squeezed

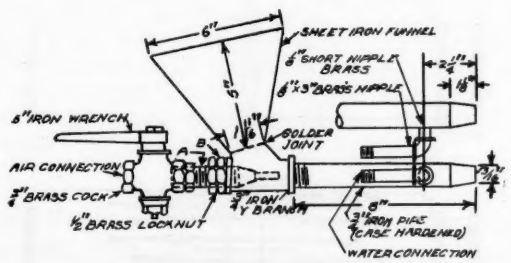


FIG. 4. SAND BLAST NOZZLE USED IN REMOVING SCALE

dry by hand. Under particularly unfavorable circulating water conditions where fabric and even fiber packings have deteriorated rapidly, metallic packing is being tried out. Such metallic packing consists of rings built up of many spiraled layers of thin babbit foil, so that, while they are of metallic construction, they are at the same time flexible and slightly plastic.

Fabric packings must not be drawn up too tight, especially where soft metal tubes are used, because of the danger of crushing the tube. The packing should, furthermore, allow a certain amount of longitudinal movement of the tube which results from expansion due to temperature changes.

Water Leaks

Water leakage in condensers is a condition which, although of considerable importance, in a great many cases has been overlooked. Especially in plants where expensive equipment has been installed for the purification of make up water, the loss due to contamination of condensate by circulating water leaking into the steam space of the condenser may be considerable. For this reason it is advisable to test the condensate from time to time by a suitable chemical method.

In seaboard stations where salt water is used as a cooling medium, the silver nitrate test will give a good indication as to the amount of leakage. This test is made by adding a few drops of silver nitrate solution to a small amount of condensate. If no appreciable precipitate is formed it may be assumed that the condenser does not leak. If much salt is present, a white precipitate known as silver chloride will be formed.

A more accurate test and one which will give the exact amount of leakage may be made as follows: To 50 c.c. of condensate add two or three drops of a saturated solution of potassium chromate. Now add silver nitrate solution (9.6 grains of silver nitrate to a liter of water) drop by drop, at the same time stirring the solution, until the color of the mixture changes to a faint red tinge. The drops of nitrate solution should be counted as they fall, stopping with the first indication of change in color. The circulating water is then tested by taking 50 c.c. of a 1 per cent solution of raw circulating water (1 part circulating water to 99 parts pure water) and testing this mixture in the same manner

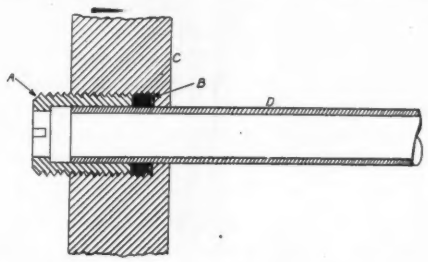


FIG. 5. DIAGRAM OF TUBE END, SHOWING METHOD OF PACKING

as described for testing the condensate. The number of drops of nitrate solution necessary to turn the color of the raw water should, however, be multiplied by 100. If, therefore, it takes 600 drops to turn the color of the raw water and 3 drops to turn the color of the condensate, the leakage is equal to $3 \div 600 = 0.5$ per cent.

If much leakage is shown to be present, the next step is to determine definitely where the leaks are located. There are two ways of doing this. One way is to fill the steam space with water and then by means of a small hand pump put the condenser under a light hydraulic pressure. In this manner the leaks will be made known by water dripping out at the tube ends.

The method just described requires considerable time. A more rapid method is to exhaust the air from the condenser by means of the air pump and then testing all joints and tube ends for tightness by means of a candle or torch. If leaks are present, the flame will be drawn in.

Most water leakage occurs at the points where the tubes are secured to the tube sheets, and is generally due to the use of poor or worn packing, corroded tube ends, poor workmanship in drilling the counterbores or to the fact that the ferrules are not screwed down sufficiently tight. Repacking with a good grade of packing

material selected to withstand the deteriorating effects of the particular circulating water in use, will generally eliminate the trouble. If the trouble is due to electrolytic action, the use of metallic packing may be found satisfactory. Metallic packing being a conductor establishes positive electrical contact between the tube sheet and tube ends and thus prevents electrolytic action from taking place.

Air Leaks

If a supply of compressed air is available, a condenser can be tested for air leaks by filling the steam space with air at about 10 lb. pressure. If a candle flame is now brought near the joints, leaks will be easily disclosed. A still more delicate indication may be obtained by smearing soap suds over the suspected places and noting whether bubbles are formed.

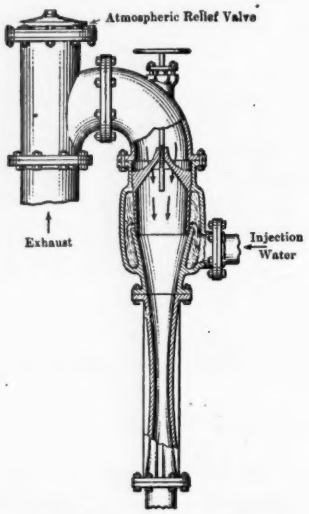


FIG. 6. TYPE OF BAROMETRIC CONDENSER NOT REQUIRING THE USE OF A DRY AIR PUMP

Leaks in the piping connected to the condenser may be detected by the air pressure method described in the foregoing paragraph or may be located when the condenser is in operation, by bringing a candle flame in close proximity to the joint. In this case the flame will be drawn in towards the joint due to the air entering the system at that point.

Leaks at the joints may be repaired permanently by remaking the joint. This, however, is often inconvenient by reason of lack of time and such leaks may be stopped temporarily by calking with cotton batting or by filling the opening with red lead putty and fitting a clamp over the joint to keep the putty in place.

Removing Air

The operation of the condenser is based upon the fact that a certain quantity of steam at a certain pressure and temperature occupies a much greater volume than that same quantity of steam does when it is changed into water. At a temperature of 120 deg. F. which is often used in condensers, the specific volume of steam is 203, while water at that temperature has a specific volume of only 0.0162. It is thus obvious that if exhaust steam is condensed in an enclosed vessel, a partial vacuum will result.

Steam, however, contains a certain amount of non-condensible gases which are liberated when condensation takes place. These gases consist mostly of air and must be removed from the condenser as rapidly as they are formed, otherwise the vacuum will be destroyed. It is for the purpose of removing this air, that the dry vacuum pump is installed.

In any type of jet or barometric condenser where the use of a dry air pump is necessary, the air connection is best made at or near the top so that the air, as it leaves the condenser, will come in contact with the cooling water just as it enters. This is known as the counterflow principle and results not only in lowering the temperature but also in causing the condensation of a great deal of water vapor accompanying it.

In some types of condensers, such as is shown in Fig. 6, use is made of the ejector principle and no vacuum pump is required. Exhaust and injection water mix as shown, the quantity of injection water being regulated by the hand wheel on top of the condenser. The mixture flows downward through the narrow neck and the velocity attained in this part of the tail pipe is so high that all air and similar gases are swept along with the current.

Repairs

In the installation of condensers, particular attention should be given the method of support. Care must be taken to provide for the alternate expansion and contraction due to temperature to which the condenser may be subjected. Neglect to do so may eventually result in serious trouble due to the cracking of the shell.

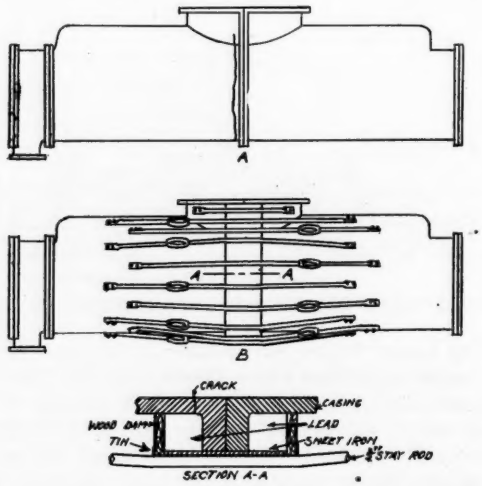


FIG. 7. METHOD OF REPAIRING CRACKED CONDENSER SHELL

If through neglect or other conditions, the shell should become cracked the unit may at times be repaired temporarily and operated until a new one can be installed. One way of making a repair of this kind is shown in Fig. 7. In this case, the shell was cracked approximately in the center as shown in the upper sketch. A new condenser could not be secured at the time due to war conditions and repair was made in the following manner. A sheet iron band ¼ in. thick and 10 in. wide was placed around the greater part of the

shell, the vertical center flange serving as a separator between this band and the outside wall of the condenser. Over the band and with the sides turned inwards to form a backing for a wooden dam carried around the girth of the shell was placed a covering of tin which, together with the iron band and the various sections of the dam, was held in place by ¾-in. stay rods.

Each of these was provided with an adjustable turn buckle and was secured to the shell by short machine bolts for which holes were drilled and tapped. After all was in readiness, the space between the outer wall of the shell and the iron band was filled with about 900 lb. of molten lead, the wooden dams serving to retain the lead while still in the molten state. After the covering was cut away and the dams removed, the tension on the stay bolts was taken up to secure the lead properly and provide an air tight joint.

Cracked condenser shells, however, are uncommon and by far the greatest amount of trouble is encountered in failure of the tubes or tube ends. Condenser tubes, when they fail, do not, as a rule, permit of being repaired, and the only remedy for such failure is replacement. It may not always be convenient to shut down a condenser merely to replace one or two split, broken or corroded tubes, hence it is common practice in cases of this kind to plug the broken tubes at both ends with wooden or rubber plugs. In this manner the defective tube will be cut out of service and the condenser may be operated until a more convenient time is had for permanent repair.

Care of Heating Systems

Points to Be Watched in the Operation of Hot Water, Steam, and Hot Air Heating Systems

TO MAINTAIN a heating system in good operating condition requires little care beyond keeping it clean and making an occasional adjustment, provided that the layout of the system was properly made in the first place. A poorly designed installation may necessitate constant experimentation and alterations to determine the most efficient, the most economical operating conditions.

There are, of course, many varieties of heating systems which may be classed in three general groups; steam, hot water, and hot air, each of which must be dealt with in a different manner. In order that the operating engineer may have a perfectly clear conception of the operation of his particular system, he should provide himself with a detailed diagram of his installation showing the location of all apparatus, fittings, valves, etc., and in order that he may be familiar with all of the parts of the system, he should have at hand detailed drawings of all these appliances.

Steam Heating Systems

Steam systems may be classed as single-pipe; single-pipe relief, overhead distribution; two-pipe, wet and dry returns; air line, vapor; atmospheric; vacuum return; etc. Any of these may be operated on exhaust steam from prime movers, on reduced high pressure, or by a separate low-pressure boiler.

Failure of these types to function properly is most frequently caused by air binding at the radiators, due usually to the air valve being out of adjustment. Excepting in the air line, vacuum or vapor systems, air accumulated in the radiator is discharged through the air valve to the room and it is a comparatively simple matter to make repairs. Trouble is due to scale or other foreign particles becoming lodged between the expanding element and its seat. A remedy is effected simply by cleaning. In extreme cases, the expansion element may have been injured, in which case it will have to be renewed. It is scarcely ever necessary to provide an entirely new fitting; a new post will be all that is required.

In systems where air is removed through return piping, this line should be broken at the union nearest the radiator so that the amount of vapor passing the valve may be noted while adjusting it. The valve should be so set that there will be the least trace of vapor issuing from it when the radiator is filled with steam. This inspection will require a little extra time, but once it is properly adjusted there should be no need for subsequent alterations.

In a vacuum system, failure of the automatic return valve to function will cause trouble by allowing air and condensate to accumulate.

Simply tapping the valve will frequently be all that is required to start it working; in other cases it may have to be disassembled to get at the trouble.

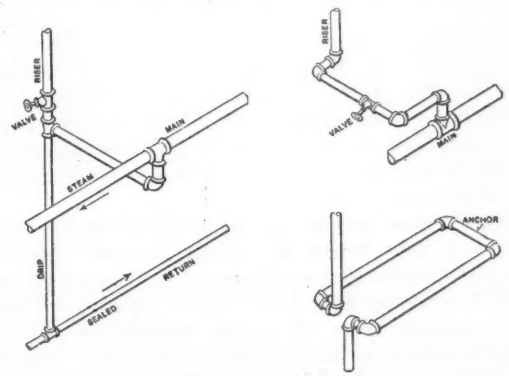


FIG. 1. CORRECT METHODS OF MAKING CONNECTIONS FOR, 1, SINGLE PIPE UPWARD SUPPLY RISER, 2, SWIVEL JOINTS, AND 3, EXPANSION RISER LOOP

Pressure carried in a low-pressure system should be kept at the lowest point that will insure adequate circulation in the most distant radiators, which should not, with well designed piping, exceed one to three pounds. Both reducing and back-pressure or atmospheric relief valves should be inspected occasionally to make sure that they are in working order. Usually the latter valve is located on the main exhaust riser near the roof and is likely to be neglected unless a special point is made of inspecting it periodically. If this valve fails to open, a high back pressure may be thrown on the engine

during periods of light heating loads, or, if it fails to close, a serious waste of steam will result.

In an exhaust system, sufficient quantities of oil may accumulate in the radiators to impair seriously the amount of heat that may be dissipated, unless there is an efficient oil separator in the line from the engine. Obviously this separator should be well drained and trapped to accomplish the desired results.

One of the objectionable features of certain types of steam systems is their liability to give forth loud crackling noises at times. In a well piped installation this should be impossible, but it occurs at times, seemingly in spite of everything. The cause is absorption of steam by cold water in the line, which of course should not be allowed to exist. Examine the piping to see that the grading is correct so that no pockets may be formed and all condensate may readily drain off.

Condensate and boiler feed pumps should be kept in the prime of condition; valves should seat properly, shafts should be carefully alined, and the whole should be kept well lubricated. If direct acting piston pumps are employed, care should be taken to see that they are constantly on the job. Duplex pumps are not likely to stop, but pumps of the simplex type are liable to give trouble in this way, due to air binding, unless constantly watched.

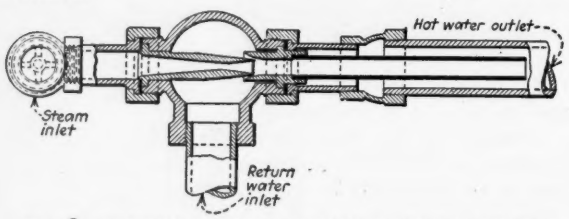


FIG. 2. SECTIONAL VIEW OF STEAM JET WATER HEATER

If return, lift and feed traps are used, they should of course be kept in operation. To facilitate inspection on this point, traps should be of such construction that in the act of discharging there will be some accompanying mechanical movement that is visible to the operator, so that he may see at a glance whether or not the apparatus is working.

Single pipe systems are particularly subject to this crackling noise known as "water hammer" especially where the steam and condensate flow through the same main in opposite directions. If the piping is of insufficient capacity there will be an interference, the water will be picked up and driven to the end of the main with this characteristic noise. The difficulty may be eliminated by pitching the main away from the boiler and adding a wet return line. In some cases, the installation of a larger main will serve the purpose.

When shutting off a radiator on such a system, the valve may not seat tightly, thus allowing steam to leak into the radiator, but preventing the condensate from draining off against the steam flow. Water thus accumulates in the radiator and when the steam is again turned on, violent hammering will result. It may be that care was not exercised by the user in closing the valve, in which case the engineer may be called upon to instruct the tenant on the art of closing valves. There is the possibility, however, that the valve may have an imperfect disc or seat, which, of course, calls for a repair or a renewal.

When heavy insulation is used on small diameter pipes, the load is sometimes excessive and the pipe sags under the weight, thus forming a pocket in the line where condensation may collect and cause annoyance due to water hammer. The remedy is to remove the covering, straighten the pipe, and put in more supports, after which the insulation may be replaced.

Frequently water hammer is caused by poorly made radiator connections. In general, the branches should be of ample size to permit the flow of steam and water at the same time without interference. The connections should not be direct, but should be offset so that there will be room for expansion. For the same reason, connections between risers and mains should be indirect. Risers should be provided with expansion loops to allow for sufficient movement without unduly distorting the branch connections. Figure 1 shows examples of such construction.

For large installations, vapor, vacuum or air line systems are usually preferred on account of the better regulation possible. Each of these has a vacuum return which necessitates a suitable pump or vacuum trap, which complicates operation more or less and requires more careful watching. In the vapor or vacuum systems, various forms of thermostatic traps or valves, thermotors or retarders are employed to allow passage of air and water to the return line but to prevent steam from blowing through. Such valves must be kept clean and in good working condition if the best results are to be expected. On vapor systems, the radiator is controlled by regulating the steam supply. This regulating valve should be so set that the maximum opening will not pass more steam than can be condensed in the radiator, otherwise steam will blow through into the return line and will have to be condensed by a water jet before the pump will handle it.

The ordinary vacuum system uses a slight vacuum, only sufficient to remove the air from the high points in the system. If, however, such a system is run on exhaust steam, it may be desirable to increase the vacuum to reduce the back pressure on the prime mover. By increasing the capacities of the vacuum and condensate pumps, such a system may be converted into the equivalent of a condenser for the engine. A vacuum as high as 22 or 23 in. of mercury may be maintained at the pumps which will result in a vacuum of some 10 in. at the engine. The effect is really an air-cooled condenser. If the system is of insufficient capacity, a regular condenser may be used in series with the heating system to obtain the desired reduction of pressure at the engine.

Hot Water Systems

In effect, the same results may be obtained by a hot water system. In this case the water used for heating is heated by contact with exhaust steam which is thus condensed as in the ordinary condenser, the heated water, taking the place of the circulating water of the usual steam condenser, is then circulated in the heating system to have its heat abstracted in the radiators. Otherwise the system is identical with the ordinary hot water heating system.

Hot water systems may be considered in two groups, gravity and forced circulation. Either may be of the single or two-pipe system. In the one-pipe system, the radiator simply forms a partial shunt around the riser

or main and the relatively cool water that has passed through the radiator mixes with the warm that has passed only through the main and goes on to the next radiator. In such an installation, the last radiators on the line receive comparatively cold water and may not give off sufficient heat. This condition may be altered by increasing the surface of the last radiators or by limiting the maximum valve openings in the branch line to the first units.

The two-pipe system, though more costly to install, has a more positive circulation and on that account is to be preferred. This system must be so designed that the resistance to flow through each circuit should be the same, otherwise low resistance lines will hog the greater part of the flow. It is almost impossible to make this balance accurately beforehand, hence a throttle valve should be placed in each circuit, if there is complaint of cold radiators in any part of the system, in order that the flow may be regulated to suit conditions.

If it is found that the gravity system cannot circulate enough hot water to maintain the desired temperature, the flow may be increased by installing a circulating pump in the return line near the heater. Another method would be to increase the temperature of the water by increasing the pressure on the system. The more common installations are operated on what is known as the open system; that is, they are under atmospheric pressure which means, of course, that the maximum temperature which may be realized is 212 deg. F. By changing over the system to a closed type, the pressure may be increased. This may be accomplished by inserting in the expansion riser what is known as a generator, which is simply a mercury seal. It consists essentially of a "U" tube filled with mercury, one leg being connected to the system and the other to the expansion tank.

When the temperature of the system rises, the water expands and exerts an increasing pressure on one leg of the tube, causing the mercury to rise in the other leg, thus increasing the pressure by an amount equal to the difference in the height of mercury in the two legs. The insertion of this generator prevents circulation of water in the expansion tank, which, if located in an exposed position, must be warmed to prevent freezing. This tank may be heated by a closed coil with both intake and outlet to the system below the generator. The connections would be the same as for any of the radiators.

In buildings equipped for hot water heating where the requirements have increased beyond the capacity of the heater, live steam may be used to make up the deficiency if it is available. By inserting a steam jet such as shown in Fig. 2 in the main from the heater, steam may be mixed with the water, thus raising its temperature the desired amount and incidentally increasing the flow, both of which effects will increase the amount of heat that can be given off at the radiator. In case one jet is insufficient for the purpose, two or three or more may be installed in parallel.

Regulation can then be obtained by using one or more jets as the weather conditions require.

In central heating plants or in institutions where more than one building is heated by a single system, efficient transmission is a serious problem with either steam or hot water. Heat losses must be reduced to a minimum. When water, gas, and electricity are distributed from a central point, a concrete tunnel is usually provided in which the heating lines may be placed.

If the heating mains must be run separately, care should be taken to see that they are well insulated and water proofed, and the trench well drained. The insulation and proofing may consist of one layer of asbestos, a good sized air space, a wooden stave pipe lined with tin with inside diameter sufficient to accommodate easily the pipe flanges, an outside covering of tar paper and asphalt. A section of such a conduit is shown in Fig. 3. Expansion joints or loops must be placed in this line, preferably in the middle with an anchor at each end. If the distance covered is considerable, more than one will have to be installed. Thermometers should be inserted in each end of the line and their readings noted occasionally. If an abnormal drop occurs from one to

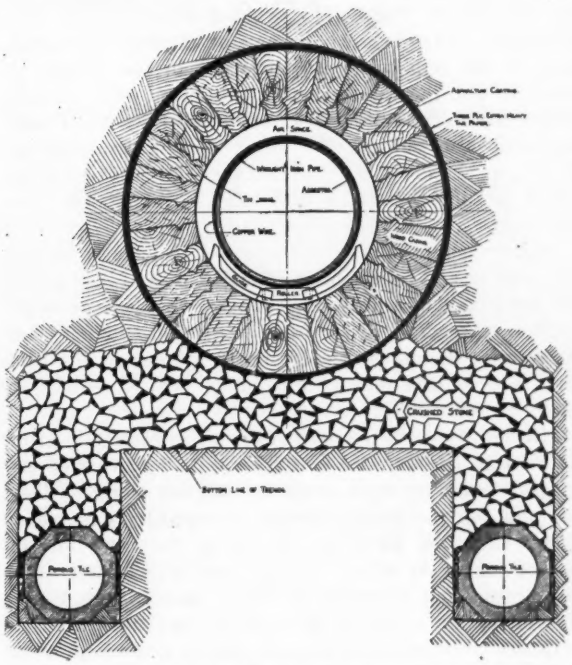


FIG. 3. APPROVED METHOD OF LAYING UNDERGROUND HEATING MAINS

the other, the insulation should be investigated and if necessary renewed.

Overhead lines are sometimes used, but only for comparatively short distances or where it is impossible to go below the surface. The great disadvantage of this method of transmission is the increased radiation losses that result. On the other hand it is usually less expensive and less subject to deterioration. Where appearance counts for anything the line should be below the surface as an overhead line is always unsightly.

Hot Air Heating and Ventilating

THE ONE great difficulty with either hot water or steam heating is that no ventilation is secured. This is a most important consideration in any building and should not by any means be overlooked. Warm air furnaces are ordinarily used only in small houses where the length of the horizontal leads does not exceed about 15 ft. They require but little attention and are not

properly within the province of the engineer. Hot blast systems are suitable for large installations in connection with hot air furnaces but usually such systems are heated indirectly by either steam or hot water. In some kinds of factories, in most public buildings and occasionally in private homes, some means of regulating the humidity is used in connection with the heating system. Air is drawn in from the outside, passed through a bank of tempering coils, to raise its temperature above freezing in cold weather, then through a spray where most of the dust is washed out. After this the air passes through a series of baffles and is then blown past a bank of heating coils to the various registers in the building.

Tempering coils are used only in freezing weather, otherwise they are dead. Care must be taken to prevent an unexpected temperature drop from freezing them where there is no circulation. If of the steam type, they should be thoroughly drained when not in use. When hot water is used, it may be allowed to remain dead in the coils when they are not in use if care is taken to put them into service the minute the outside temperature drops to 32 deg., otherwise they will freeze and will also subject the spray system to freezing. Usually such coils are controlled by thermostatic valves which should be tested occasionally to make sure they are in operating condition.

Spray nozzles must be inspected frequently to see that they are all functioning. Small pieces of dirt which are apt to get into the system may easily clog the small nozzles. An effective strainer with mesh smaller than the nozzles should be placed in the system on the suction side of the circulating pump, which should be cleaned periodically.

Baffles placed in the path of the air immediately after its passage through the spray serve to remove any entrained moisture that may be carried along. They are built on the same principle as separators in steam lines; i. e., by suddenly reversing the direction of flow of the air, to relieve it of moisture which has greater momentum and therefore tends to maintain its direction of flow to a greater extent than does the air. This moisture collects in grooves and drains to a sump below which must be kept well drained.

At this point the air enters the suction of a fan of the centrifugal or propeller type and is discharged through the heating coils to the ducts that convey it to the desired points. The heating coils may be of any of the types mentioned previously and the same care should be taken for their proper maintenance.

Fans or blowers will not, as a rule, require much attention. Once a year they should be surveyed to see that the shaft lines up properly with the driving engine or motor. Bearings, of course, should be kept well lubricated the same as any other piece of machinery. In installations where no air washer is provided, considerable dust may accumulate on the blade which should be removed periodically.

Frequently such installations are provided with return ducts which return a portion of the air to the heater and discharges the rest to waste. The position of the mixing damper, which regulates the relative amounts of fresh and recirculated air being used, should receive careful attention to prevent the air from becoming stale.

Such systems are more or less elaborate and are frequently made entirely automatic in operation, all operations being thermostatically controlled. This, however, does not relieve the engineer of all responsibility for the proper operation of the unit. He must always be certain that the automatic controls are in operating condition.

Humidity is controlled by saturating the air at such a temperature that when it is heated to the desired room temperature it will have the desired humidity. For instance, if air at 70 deg. is required to have a relative humidity of 50 per cent it must contain about 55 grains of moisture per lb. of dry air. It is found then, from humidity tables, that air containing this amount of moisture is saturated at about 52 deg. The air passing through the spray must then have this temperature, which means that in summer weather it must be cooled by refrigerating coils which should be installed in the system ahead of the tempering coils. The spray water will also have to be cooled slightly below the saturation temperature. The cool air will then have to be heated to the correct temperature before it is distributed throughout the building. A close watch must be kept on water and cooling coil temperatures if consistent results are to be obtained.

It is essential to the successful operation of a closed circulating system that all windows, doors and other communication with the outside be kept closed. Tenants are prone to forget this point and it is therefore up to the engineer to constitute himself a police force, along with his other duties, to see that regulations on this point are complied with.

Heating With High Pressure Steam

Heating systems that are operated in connection with the generation of power, utilize the exhaust steam from the prime mover when that machine is in operation, but, during the night when, usually, the engine is shut down, steam for heating must be obtained from some other source.

Ordinarily, at such times, steam is taken from the high pressure boiler through a reducing valve. In undergoing this change of state the heat content of the steam remains virtually constant, in which case if the pressure drops the steam must become superheated. Experience has demonstrated the fact that, for purposes of heating, where condensation is desirable, superheated steam does not compare with saturated, as it does not as readily condense in the radiators. It is expedient then that the superheat be removed before the steam is allowed to pass into the heating system.

This result has been accomplished by simply passing the steam direct from the reducing valve to an open feed water heater, which may be subjected to a back pressure. In passing through the rain of water over the trays of the heater, the steam has its heat content reduced by an amount sufficient to reduce it to the saturated state. Further, some of the water will be evaporated and the steam thus formed will pass along to the heating system.

In installations where there is sufficient auxiliary exhaust available to maintain the feed water at the desired temperature, the superheated steam is passed, instead, into a large tank which is half filled with water, from which the heating system is supplied.

Coal and Ash Handling

MEANS EMPLOYED AND OPERATING PRECAUTIONS

HANDLING of coal and ashes should be separated, as the machinery for the coal side is of greater capacity and cost than that for ashes, and it will be rapidly worn by handling the abrasive ashes and clinkers.

With the present cost of labor, it is only the smallest of plants which can afford to handle coal by hand, but for the smaller amount of ashes, hand removal will often be the cheapest method. Where permanent apparatus has not been installed for storing, reclaiming and bunkering coal, portable conveyors can always be adapted for the work with advantage in reduction of labor and cost. A combination of inclined portable conveyors for short distances and telpher bunkers on cableways, or drag line scrapers for long distances is effective and flexible.

For permanent installations in large plants, a combination of belt and bucket conveyors is most common with some form of crane and clam-shell bucket for storing and reclaiming.

In present practice, electric motors are usually the driving power, and they should be of enclosed type, but

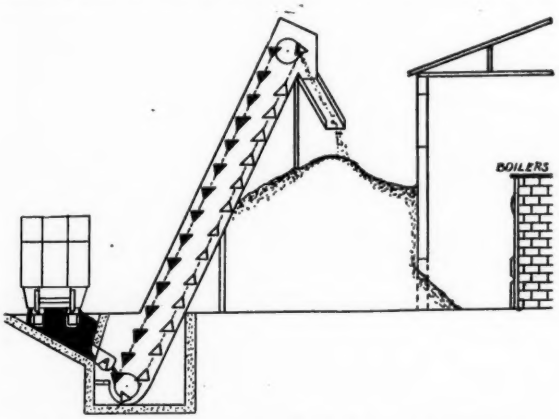


FIG 1. CONVENIENT BUCKET ELEVATOR SYSTEM

even then should have frequent inspection and careful attention as the service is severe. Gearing and parts of the machinery are always rugged so that they need little more than occasional inspection, and renewal when they show excessive wear, but bearings should be kept well lubricated and tracks or guides in alinement to avoid unnecessary wear.

For extensive systems, push buttons should be provided at convenient locations so that the conveyor may be stopped in emergency from any point along its run; but starting should be possible only from a point near the driving machinery. Control of the crusher and its attendant conveyors should be so interlocked that when the main conveyor stops, the crusher installation will be stopped to avoid jamming.

When starting up, men should be stationed at the receiving and unloading points to make sure that the machinery is operating properly.

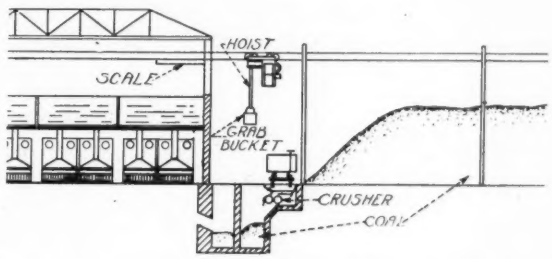


FIG 2. TELPHER SYSTEM FOR STORAGE, RECLAIMING AND BUNKERING

Often bunker capacity is diminished by setting the delivery run of the conveyor too low. It should be possible to heap up the coal at the center until the sides are nearly full. The angle of repose may be taken at 35 deg. and the conveyor set at a height to allow heaping at that angle. To avoid overfilling, an alarm is suggested as shown in the illustration.

Chutes for delivery of coal should not flare at the outlet, as this tends to throw the large coal to the sides and cause an uneven fire. The end of the chute should be straight, and distribution in the stoker hopper accomplished by moving the chute as may be necessary.

To get maximum capacity from a conveyor, the bucket type may be speeded up to 70 ft. per min. for short runs and lifts, or to 40 ft. per min. for longer conveyors; but care should be taken that the motors are not overloaded, and it is better to keep the installation running on a schedule which will not require forcing.

For belt conveyors, the maximum speed is 300 ft. per min., the inclination 20 deg. from horizontal and the loaded run of belt should be supported at 3 to 6 ft. intervals by idler troughing pulleys. The return run is usually flat with idlers at 6 to 12 ft. according to the weight and size of belt.

When using belt conveyors, several points need careful attention, if the maximum of service and durability is to be secured and the following hints by J. B. McPherson will help. Pulleys on both loaded run and return should be in line to avoid climbing and undue

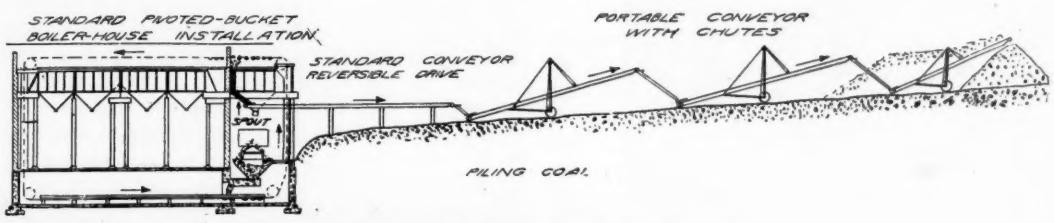


FIG 3. PORTABLE CONVEYORS FOR STORAGE

strain; the belt should be laced at proper tension and with even tension all the way across, no uneven or ragged ends being permitted; the belt must not rub on any stationary object at any point or chafing will destroy the cover.

When operating, do not stop the belt loaded if it can be avoided; especially if handling hot material, and if a stop has to be made, unload the belt before starting. Hot material should be unloaded at once, or the belt cated; a warn or stuck bearing may cause serious damage to the belt.

If the cover of the fabric becomes cut or abraded, repair it at once the same as an automobile tire to prevent further damage.

A few kinks in installation may save much grief.

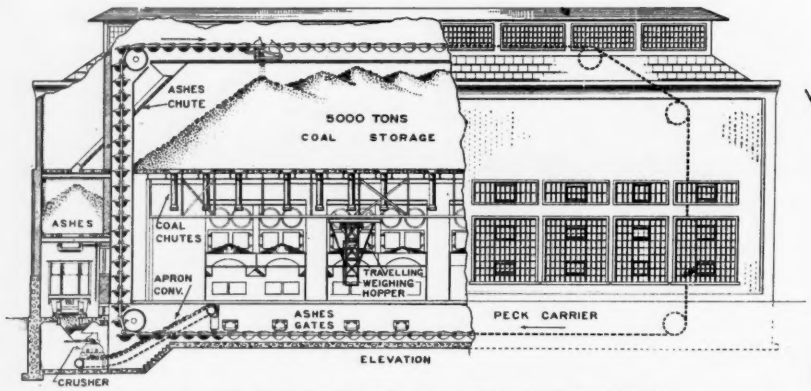


FIG. 4. PERMANENT BUCKET CONVEYOR INSTALLATION

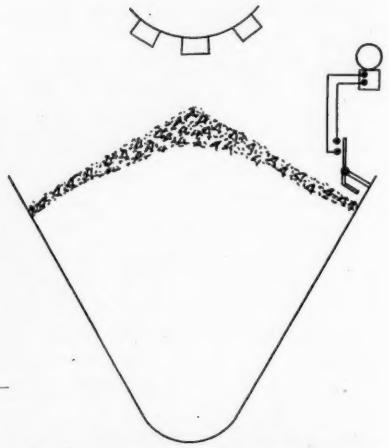


FIG. 5. ALARM SYSTEM TO PREVENT OVERFILLING BUNKER

may be ruined. Overloading the belt produces excessive strain, while running underloaded wastes power; both should be avoided.

When lining up pulleys, work in the direction of travel, starting from one end; the pulley which is causing climbing may be two or three spaces away from the point where climbing occurs. Be sure that head and tail pulleys are large enough, at least 4 in. of diameter for each ply of belt. And keep pulley bearings well lubri-

Usually it is large material that causes abrasion of belt surface; hence when handling unsized material it is well to use a screen in the bottom of the chute as in Fig. 7, so that a protective layer of fine material will be laid below the larger sizes. All material should flow to the belt in the direction of motion and as nearly as possible at the speed of the belt. If the material falls some distance, baffles should be placed in the chute to break the impact.

FIG. 6. BUCKET ASHES ELEVATOR FOR LOADING CARS

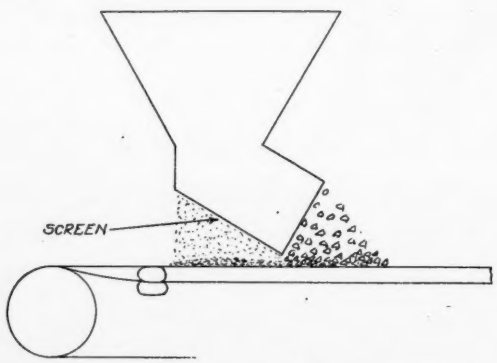


FIG. 7. SCREEN IN CHUTE TO GIVE PROTECTIVE COVERING OF FINE MATERIAL

If material bounds and scatters from the belt, it is liable to get on the return run and be caught between the belt and the tail pulley, causing serious damage. To prevent this, the use of skirt boards, Fig. 8, is desirable, placing the boards so that they cannot touch the belt, and setting the bottom at a slight angle with the belt in the direction of travel so that lumps cannot wedge between the boards and the belt. A piece of old belt, set so as to touch the return run ahead of the tail pulley and at an angle to the line of travel, will sweep off any material which may have collected on the return side.

Machinery for handling ashes should be the simplest possible, as it is subject to abrasive wear. In large plants hoppers below the boiler provide for 24 hr. accumulation, but in smaller plants the ashpit should be cleaned at least every 12 hr. For the hoppers, removal is easy, as space is provided for some form of barrow or car to receive the ashes from the hopper spout. Spraying the

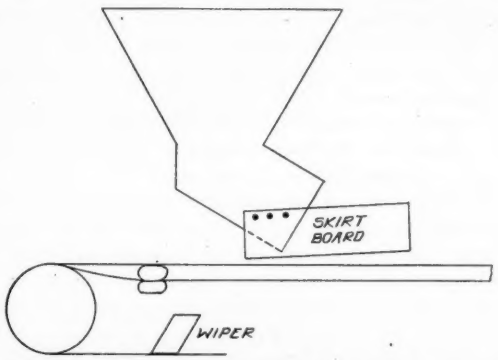


FIG. 8. SKIRT BOARD TO PREVENT SCATTERING AND WIPER FOR RETURN RUN

ashes in the hopper reduces the dust and heat of handling and the abrasive effect.

Where hoppers are not provided, a scraper, a bucket conveyor, or a pneumatic or steam ejector system will usually pay in reduced labor cost. For conveyor handling, the ashes should be wet before removal from the ashpit; but for the ejector system they must be handled dry or nearly so, although a spray may be used near the discharge end of the system to reduce dust at the outlet.

Difficulty in operation of an ejector sometimes arises from too small a steam supply or from bad location. A steam system should operate on from 250 to 350 lb. of steam per ton of ashes, according to the length of carry and the lift. It is usually better to draw the ashes from all inlets by suction and to discharge by the blowing force of the jet. The line should be kept air tight except at the inlet openings, and wearing pieces inspected occasionally to insure that the main pipe is properly protected by them.

The same machinery should be usable for both storing and reclaiming coal, and storage space provided for an amount that will cover any probable interruption of supply. It is well to use up and replace the stored coal at intervals, to avoid likelihood of combustion and deterioration, although tests have shown that for eastern and central coals, the loss of heat value is not over 2 per cent over a period of 2 yr. Storage and reclaiming do, however, involve some expense, hence working over the storage piles should be done only as found necessary. This cost will vary according to method of handling and amount handled from 5 cents up to 40 cents a ton.

Breaking Ammonia Joints for Repairs

METHOD OF MAKING AND BREAKING PIPE JOINTS IN INSERTING NEW SECTIONS. BY J. J. COSGROVE

WHEN SPEAKING of a refrigerating system, an ammonia system is so generally understood that it might seem superfluous to state that this article deals with ammonia systems only. This in no way disparages the carbon dioxide or other machines. It is due to the fact that what is said about one system would not apply to another, so of necessity the different systems must be treated separately.

The element which makes the breaking out of an ammonia system more interesting than the breaking out of any other kind of a piping system, such as steam, water or compressed air, is the danger to life from the ammonia should it not be exhausted from the system. Ammonia will kill. Carbon dioxide, while it can, in practice is not likely to.

We will assume that there is defective piping in an ammonia system which has to be replaced. The first thing would be to select a time when the system can be shut down for the required period with the least loss or inconvenience. Then, to tide over the period of shut-down, build up the refrigeration. That is, chill the brine more than is the general practice, so that it will not heat too much during repairs.

When all is ready and steam is cut off from the compressor, close the suction valve, also the liquid valve in the liquid line from the receiver to the expansion coils and the expansion valve. If these are not closed, the liquid will accumulate in the expansion coils and the suction line and make trouble when starting up again if it is not pumped out.

Of course the engineer will pump out that part of the system to be repaired before breaking out the line, and pump it out thoroughly. He will also be sure the pressure is off before opening up an ammonia joint. It is advisable to open up some blow-out valve, the charging valve or the valve on the oil trap to make sure that the pressure is all out.

Even then, it is well to open up the first joint leisurely. Loosen the bolts a little at a time and break the joint gradually without separating the parts until you are certain that the pressure is off. By this procedure, in case there should be pressure on the system, you can draw the parts together again before the leaking ammonia becomes too strong and drives you away.

Repair men should be provided with ammonia helmets; not necessarily to wear while making repairs, but to have on hand should emergency require them. It is not only when breaking out a line that the helmets will be convenient, but when purging the system, when a leak develops or a blowout occurs. The helmet is in the line of prevention and nowhere is the policy of safety always more to be considered than in refrigerating practice. Next to prevention comes first aid or remedial measures, and one of the first things workmen

around ammonia refrigeration systems should learn is something about the nature of ammonia, its effect upon the human system and how to treat a patient exposed to its fumes.

One of the most frequent instructions to a new workman around a plant is not to get excited in case a co-worker or any one else gets a dose of liquid ammonia or ammonia-saturated oil. They are instructed to douse them with water; turn the hose on them if one is convenient.

All very well as far as it goes; but they ought to know something about the nature of ammonia and how to follow up the treatment to give lasting relief.

Most corrosive substances are acids, but ammonia is an alkali. That is an important thing to remember, for therein lies the key to the treatment. The ammonia has a powerful reaction, and on account of this alkaline reaction and gaseous nature it was known to early chemists as "the volatile alkali."

Ammonia is a suffocating gas, having a marked effect on the air passages and lungs. The valve guarding the air passage to the lungs closes spasmodically when the attempt is made to breathe it. Notwithstanding this spasmodic closing of the wind pipe, the action is not quick enough to prevent some ammonia from reaching the lungs when the gas is present in large quantity and the feeling of suffocation is extremely agonizing.

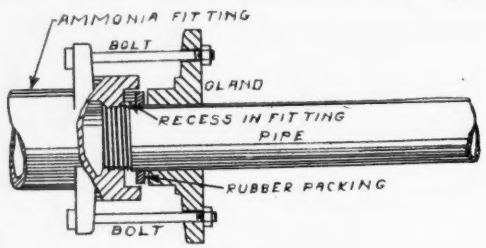


FIG 1

FIG 2

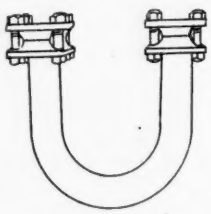


FIG.3

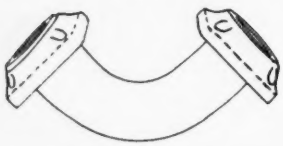


FIG. 4

FIG. 1. TYPE OF JOINT ORDINARILY EMPLOYED IN AMMONIA LINES

FIG. 2. OVAL TYPE FLANGE WHICH IS USED EXTENSIVELY

FIG. 3. TYPICAL 90 DEG. BEND

FIG. 4. RETURN BEND WITH SQUARE FLANGE AND COMPANION BEND

An old refrigeration engineer who had been "gassed" by ammonia several times told the writer that olive oil sprayed into his nose, mouth and throat gave him more lasting relief than anything else. Some of the oil spray reached his lungs when nothing else would and he recommends oil highly for that purpose. It might be well to keep in the medicine chest around refrigeration plants an atomizer for spraying olive oil into nose and throat, and a supply of olive oil.

The stomach can be reached in a more direct way to neutralize the ammonia involuntarily swallowed. As stated before, ammonia is an alkali, therefore it is neutralized by an acid. For this purpose a mild vegetable acid like lemon juice, orange juice, sour cider or vinegar and water will give quick relief. Milk and the white of eggs may also be given with benefit and the patient should be kept warm.

But returning to the mechanical, never break out a line and allow the confined ammonia to escape. It is easy to pump it out; that saves the ammonia, and it is much pleasanter working around a place that is not charged with the fumes of ammonia.

When repairs have to be made to expansion coils in brine tanks, use a blower to clear the ammonia out of the tank and supply fresh air to the man while working in the tank. If you have not a blower in the plant, you should have, and cannot purchase one too soon, for a workman should never go into a pit, tank or cavity of any kind without first changing the air inside. All that is needed is a little electric blower with flexible inlet and outlet ducts. Set this up in such a manner that it will draw a supply of pure air from the outside and discharge it into the bottom of the brine tank.

Workers in electric subways use a blower of this type and the workmen never descend into a manhole without first changing the air. Then, during the period they are below ground, they keep the blower running to maintain a fresh supply of air.

To shorten the period of shut-down, due to repairs, it is well to take measurements in advance of all piping which must be replaced, and have it cut to measure ready to install. When it is practical to do so, the pipes can be made up in sections so that all that is necessary will be to drop the several sections in place and make proper connections.

Before a pipe is put in the system it should be stood on end and hammered well to remove all grit, scale and dirt that might be adhering to the inside surface.

If the repairs to the refrigeration system are going to take two or more hours before operations can be resumed, tighten the piston rod packings on the compressor. The piston rod will cool and shrink in size after the compressor stops running, and if the piston rod packings are not tightened to take care of the shrinkage, ammonia will leak out between piston rod and packing. If the packing is tightened when shutting down the compressor, it will be but logical to slack off the packings when starting up again. This can be done gradually as the piston rod heats up and expands, and will insure a tight joint at the packings.

Standard weight wrought iron or steel pipe is of sufficient strength for the pressures ordinarily carried in power plant work, and is used for steam, water supply, drips, and general piping. But on account of the very heavy pressure under which refrigeration plants operate, and the necessity for having them perfectly tight, extra strong pipe is generally used for all the principal parts. In carbon dioxide systems where extremely high pressures are carried, double extra-strong pipe is required.

This, of course, is already known to experienced engi-

neers; but it has not been the good fortune of all engineers to have refrigeration practice or experience, and it is for those seekers after truth that this article is written.

It is of the utmost importance to have all the ammonia piping around a refrigeration plant perfectly tight, for in addition to the danger to health and life from inhaling the fumes, ammonia has an injurious effect on many stored products, and mixed with air in certain proportions is dangerously explosive. Then, too, leakage of ammonia is a direct economic loss, for ammonia is among the expensive commodities to buy, and it is surprising how much ammonia can be lost from a slight leak escaping continuously.

Owing to the necessity for maintaining a perfectly tight ammonia system, the ordinary screw joint and the steam and water fittings of every-day practice are not suitable for refrigeration work, either in the ammonia or the brine systems. Special ammonia fittings have been designed for this purpose. The main difference between a steam or water joint and an ammonia system pipe joint is that the ammonia is a double joint. The fitting is threaded with a standard pipe thread, and the pipe is screwed into the fitting. That gives the coils strength and presumably tightness. But presumption is not sufficient. To insure the joints against leaking a packing is used, usually a rubber packing, which is held in place with a gland. It is this gland that is removed or loosened cautiously when breaking out for repairs. Should the joint show signs of leaking, the nuts can be tightened on the bolts again, driving the gland down in place and compressing the gasket against the face of the fitting and the side of the pipe. The packings, whether of rubber or some other material, are slipped with the glands over the pipe before it is screwed into the fitting.

Instead of a gland or washer, a running thread and washer may be used in emergency, a lock nut being used to compress the packing. Backing the locknut down towards the face of the fitting acts very much as a gland would, only it has a turning motion which is apt to "chew" the gasket more or less.

Still another way of making up an ammonia joint when putting the system together after it has been broken out for repairs is to use malleable iron or steel fittings, but instead of using rubber gaskets and locknuts or glands, the threads are sweated together with solder. It might be well to add that either genuine wrought iron made by the puddling process, or mild steel, such as is used in the manufacture of steel pipe, may be used with equal safety in making repairs. Some engineers have a fancy for genuine wrought-iron pipe. Other engineers have an equally strong fancy for steel pipe. But the tests of time and tests of practice go to show that for average purposes either material may be used. There are conditions under which wrought iron will show a greater resistance to corrosion and other destructive agencies than steel. There are other cases where steel shows greater resistance and durability than wrought iron, but averaging the two materials for power house work, they may be considered equal.

Overhauling the Ice Plant

Where to Look for Defects and How They Should be Remedied

IT IS WELL, in going over the ice or refrigerating plant to make repairs or alterations, to have some definite order of procedure in mind which should be religiously followed that no item will be overlooked. A notebook or log, kept during the working season, in which are jotted down items that require attention, will prove extremely useful at this time. There should be listed all defects that crop up during the season and the repairs that should be made, together with a list of parts needed for each; installation of new apparatus that is deemed advisable, etc. The log should indicate records of daily temperatures and pressures, fuel used, ice made, storage used, supplies required, etc.

Compression System

It will probably be advisable to begin with the most important unit, the engine-compressor unit, on a compression system. First purge the system of as much foul and non-condensable gases as possible, for which purpose the proper connections are shown in Fig. 1, remove the oil from the traps and ammonia purifier and then pump down the system, returning the ammonia to the receiver, and, if necessary, to additional ammonia drums.

When it is sure that the system is empty, close both suction and discharge valves and dismantle the machine, piece from piece, until it is stripped down to the naked frame. Each part should be carefully examined as it is taken off and if any defects manifest themselves they should be repaired. See that all bearings are true, that the oil grooves and passages are free, and that the journals are not out of round. Similarly ascertain whether or not the crankpins and other pins about the machine are out of round. If found necessary, turn them down and bush them in their proper places.

If the cylinder or piston rod is scored or worn down in places, rebore or return as the case may require. It is rather a difficult thing at times to determine whether or not a cylinder is worn badly enough to justify having it rebored; in such a case, the advice would be to take off a fine cut, because in another season the difficulty would be greatly magnified and the loss in efficiency due to leaks would more than pay for the repair. If left alone, the trouble might well increase to such a point that it would be necessary to shut down during the busy season to effect a repair.

Grind in the valves and valve cages and see to it that they seat accurately, because a leaky valve is capable of causing any quantity of interference with perfect operation and a serious loss of efficiency. Make sure that the rings bear on the walls of the cylinder at all points. If they do not, it will mean that there will be an excessive amount of leakage of ammonia. In the event that a repair is needed, peen the ring out to fit

or if this cannot well be done, the whole set should be replaced.

When all the individual parts have been put in condition, re-assemble the machine, making sure that the clearance is reduced to a practical minimum and that the alinement of the cylinder, guides, crankpin and main shaft is as nearly perfect as possible.

Gages and Thermometers

Before the compressor is put in service again, the gages, both suction and discharge, should be tested for accuracy. As a check on the condition of the gas entering and leaving the compressor, it is well also to install thermometers in these lines. Thus by noting the temperature of the gas it can be compared with the temperature due to its pressure, from which it may be determined whether or not the gas is superheated.

Elsewhere about the plant thermometers should be used freely so that a check may be kept on the functioning of each piece of apparatus. Guess should be eliminated as far as possible in the operation of the plant.

Expansion coils in the brine tank, being at a comparatively low point in the system, are likely to collect quantities of oil, especially if the oil used has a tendency to congeal at the temperatures encountered on

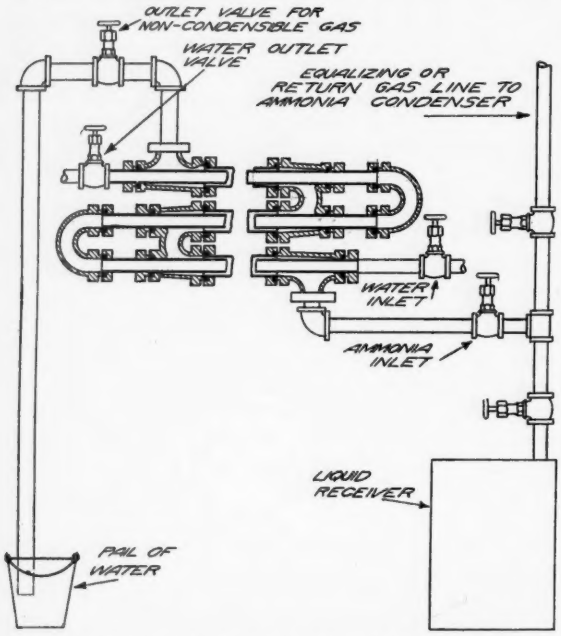


FIG. 1. PROPER CONNECTIONS TO REMOVE NON-CONDENSABLE GASES FROM THE CONDENSER

the low sides. This oil will be found coating the inside of the coils where it is effective in preventing, to a large degree, the flow of heat from the brine to the ammonia.

If the pressure in the low side has risen since the first pumping down, it means that there is still ammonia in the system; pump down again and then drain the tank of brine. If there are two brine tanks in the plant, all the cans should be taken out of both of them and the brine from one emptied into the other. In plants having only one brine tank, there is sometimes provided a pit or sump for the special purpose of receiving this brine. If no such pit is provided, barrels or ice cans may be used to good advantage.

When the tank is nearly empty, replace the can covers and then spread a tarpaulin over the whole surface and fasten it down at the edges. When the tank is entirely empty, admit steam inside the tank and allow the coils to soak for several hours in this atmosphere of steam at a temperature of 212 deg. In the meantime watch the suction gage and if the pressure rises, as it undoubtedly will, run the compressor for a few minutes to take off the ammonia gas as it is distilled off from the oil. At the end of a few hours this distillation process should have been completed and the congealed oil will be in a fluid condition.

Break a joint in the suction line close to the suction header and make a steam connection, and then break a joint on every liquid line to each coil, at the bottom. Steam can now be admitted to the coils and the oil will be blown out at the bottom. When the discharge shows no further sign of oil, the steam should be turned off and immediately afterward air at a pressure of about 150 lb. should be blown through.

The object of the air is to remove all the moisture from the coils and it should therefore be in as dry a condition as possible, that is, the relative humidity should be low. To accomplish this result, the air, before compression, should be drawn through the air precooler or dehumidifier used in connection with the can-blowing system. If this precooler is cooled by direct expansion, it cannot be used, of course, unless there is more than one ammonia compressor in the plant. If brine is used, that taken from the tank may be sufficiently cold to effect the desired result.

The compressor used for supplying air to the drop pipes will not have sufficient capacity for blowing the coils and so the ammonia compressor must be used for this purpose.

Opinions differ somewhat as to how expansion coils should be cleaned. Steam has a somewhat detrimental effect on the rubber gaskets in the joints and therefore some engineers do not sanction its use. They do away with steam altogether and use only air. In this case, great care must be exercised because a mixture of hot, high pressure air and oil vapor is highly explosive and is subject to spontaneous ignition. To reduce as far as possible the hazard, begin with low pressure air and then build up gradually as the oil is removed.

If a Nessler's reagent test on the brine in the brine tank shows no indication of ammonia, it may be assumed that all the joints in the tank coils are tight, in which case it may not be necessary to remove the brine from the tank in order to clean the coils. The procedure in this case is to heat the brine to from 150 to 180 deg. and then carry out the process as before. The chief objection to this method is that a great deal of heat is required, and it does not allow cleaning the outside of the coils, which should otherwise be done.

When the cleaning has been completed, the broken joints should be remade and a vacuum put on the system by the compressor. If the vacuum holds fairly well, it may safely be assumed that the gaskets are in usable condition and need not be replaced. It will simply be necessary to go over the system and tighten up the joints. There may still be some minor leaks which may not show up at all on the suction gage. An effective way of eliminating them is to paint all the joints while the system is under a vacuum. Atmospheric

pressure will force paint into any open pore which will become effectually sealed. Excepting where a pipe, used for transmission of heat, is badly rusted, it should not be painted, as paint acts as a fair insulator.

While the tank is empty, examine it carefully inch by inch for leaks, and satisfy yourself that the insulation is intact and in good condition. Wherever the insulating material is moldy or water logged, rip it out and put in new.

To obtain the greatest amount of heat transmission from the cans to the brine and from the brine to the expansion coils it is necessary that the brine be kept in motion. Examine the bulkheads and partitions. See that they are tight and that there is no chance of the brine being short-circuited so that it will bypass some of the cans. Examine the agitator carefully, while it is at rest, to see that the bearings and glands are in good condition and that the propellor blades are free from deposits of any kind; and, in motion with the tank empty, to see that it is in good running condition and capable of performing its work properly.

Thoroughly clean the inside of the tank, scrape off any rust spots that may be found and then paint with some good waterproof paint. When the paint is dry, the brine may be replaced but only after it has been carefully strained.

Keep the coils covered at all times so as to prevent, as far as possible, rust from forming. Some operators prefer to remove the ice cans from the tank during the winter and, after having dried them carefully, stack them away. The objection to this procedure, however, is that the depth of the brine in the tank is reduced by about half, thus leaving half the expansion coils exposed, which leaves them open to the ravages of rust. It is a question, too, whether the cans themselves will be benefited any by removing them.

Expansion coils used in ice storage or refrigerating rooms in brine or water coolers may be cleaned in the same manner described for brine tank coils.

This process of cleaning coils may be made much less difficult if care is taken during operation to prevent oil from getting into the low side. Preventive measures are always preferable to repairs. Oil may effectually be kept from the expansion coils by either or both an oil separator and an ammonia purifier or regenerator, the connections for which are shown in Fig. 2. To be effective, an oil separator must be kept drained, but even at that some coil is bound to get by in the form of vapor mixed with the high temperature discharge gases. A purifier in the liquid line will remove practically all the remaining oil, now in the liquid form, and will deliver only pure ammonia to the coils. If both these pieces of apparatus are kept perfectly clean, it may be found unnecessary to clean the coils every season.

Another item that must have attention is the condenser coils. Any accumulation of scale or oil here rapidly decreases the heat dissipating capacity and consequently the head pressure rises. Condensers should, of course, be cleaned periodically, the period depending on local conditions. There are plants employing the double-pipe system where the tubes are cleaned every day. Where fairly pure and clear cooling water is available, the interval between cleanings may be weeks or months or even a whole season. At any rate, the condenser should be thoroughly cleaned during the winter. Not only should the water surfaces be freed of scale, but also the ammonia surfaces should be rid of any oil that may have collected. Water tubes should be turbined out in much the same manner that water tube boilers are cleaned. The ammonia spaces may be cleaned by blowing with steam or by circulating a caustic solution through them. If steam is used, each tube should be blown separately.

In the case of an atmosphere condenser, the tubes should be blown down in a manner similar to that used for the double-pipe type, and the outside surfaces should be thoroughly scraped, brushed and washed down. As a uniform supply of cooling water is most essential for good results, see that the distributing troughs are level, that the serrated edges are in good condition and that the water spills evenly along the entire length.

Wind strips may well be provided between the adjacent tubes if the plant is located where there is likely to be much cross wind. These will tend to lead the water from one tube to the next and prevent it from being blown away. In well designed plants, the tube bank is so located that the prevailing winds of the district will blow along the length of the tubes and not across them.

The liquid receiver is an important item in the refrigerating plant, more so perhaps than it is generally given credit for. It has possibilities of furnishing an effective telltale on the operation of the plant. The liquid level indicator on a receiver is just as important as a gage glass on a boiler, not for reasons of safety particularly, but for economy in operation. A low level indicates that the liquid is not where it ought to be, probably in the expansion coils, flooding some of the pipes, or possibly that there is an insufficient charge of ammonia in the system.

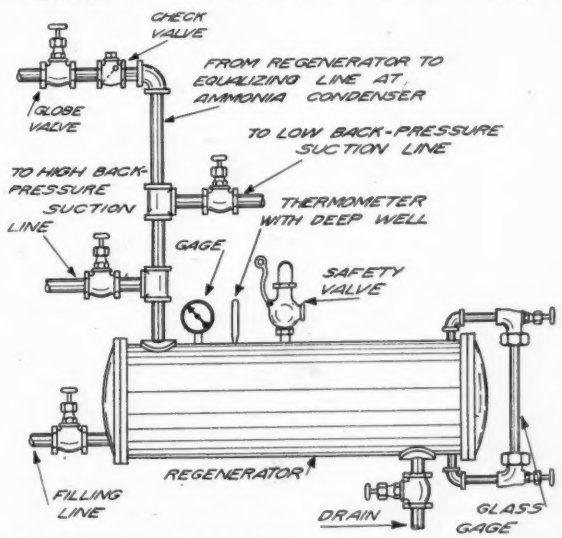


FIG. 2. CORRECT INSTALLATION OF AMMONIA PURIFIER OR REGENERATOR

On the other hand, a receiver should be kept as cool as possible in order that the liquid may be delivered to the expansion coils at as low a temperature as possible so that the ammonia in evaporating may take heat from the surroundings without having first to cool itself down to the refrigerator or brine temperature. To accomplish this result, the receiver should obviously be located in a cool place, certainly not in a hot engine room. With

this object in mind, the receiver is frequently located on the roof of the plant, under the condenser, where, of course, it is inconvenient to get at.

It is possible, however, to locate the receiver in the warm engine room so that the gage glass may be easily watched, and at the same time partially mitigate the evils of a warm atmosphere by effectively covering it with insulation. There are points on both sides of this question which will make for a different answer in each individual plant.

The receiver also serves the purpose of a trap for oil and water in the ammonia. The specific gravity of oil is less than water and greater than liquid ammonia, so that if there is oil or water in the system they will collect here in more or less well defined strata the water on the bottom, the oil next and then the ammonia on top. Means should be provided for disposing of these foreign substances, such as a drain line attached to the lowest point of the tank through which these liquids may be discharged. The liquid line to the expansion valve should terminate at a point 5 or 6 in. below the normal liquid level and at least 2 or 3 in. above the bottom of the tank. This is to prevent gas from blowing over into the expansion coils in the event of low liquid level and also to prevent oil and water from getting into this line in case they accumulate to a greater extent than should be allowed. It is well in this connection to have a gage glass long enough to include the sump volume of the tank, as shown in Fig. 3, and a marker should be placed on the glass at a level corresponding to that of the liquid ammonia discharge line.

Absorption System

In the absorption system of refrigeration, the generator and absorber, which closely correspond with the compressor of the compression system, are probably as important as any other piece of apparatus. In selecting

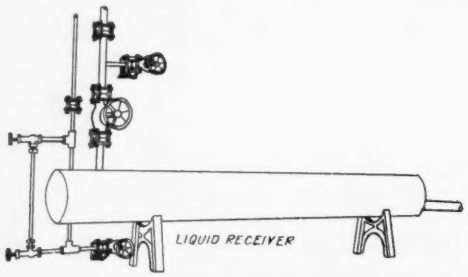


FIG. 3. LONG GAGE GLASS ON AMMONIA RECEIVER

a generator the essential point to be considered is capacity. Without sufficient heating surface, the temperature and pressure of the steam in the heating coils will have to be increased if a given rate of distillation is to be maintained. Such an increase would mean, of course, that the temperature of the distilled ammonia would be greater, a condition which does not lead to good economy any more than it does in the compression system. Foul gases will also be more readily formed and the system will have to be purged more frequently, which is always a direct loss. Furthermore, at these higher temperatures, the ammonia distillation is not as complete, more water vapor will be carried along which will impose a heavier load on both the analyzer and the rectifier or dehydrator.

Any accumulation of scale or dirt on the coils would have the effect of reducing the heating surface and care should be taken, therefore, to see that such a condition does not exist. The generator should be opened up during the winter and cleaned as well as examined.

If, during the operating season, the generator exhaust has shown any signs of ammonia, the heating coils should be examined for leaks and repaired. Such a leak means a continual loss of ammonia from the system and a continual weakening of the strong liquor.

To generate gas as dry as possible, there should not be an excessive amount of ebullition in the generator any more than in a steam boiler where dry steam is wanted, and to insure this result a comparatively large disengaging area should be available. For this reason and also for the purpose of preventing excessive corrosion of the steam coils, the aqua level in the generator should be kept above the coils.

In order that the aqua may be properly boiled, it is, of course, essential that there be a free passage of steam through the generator coils. Make sure that the steam passages are clear of obstructions and that the exhaust is free. The condensate which may be used for ice water in the distilled water plant or for boiler feed purposes should be removed as fast as it is formed so that there will be no tendency to flood the coils.

If an analyzer or dehydrator is employed as an integral part of the generator it should be inspected to make sure that the gas and strong liquor passages are free and that intimate contact between these two is assured.

The rectifier, weak liquor cooler and absorber all function in a manner similar to the condenser in that there is a heat transfer to cooling water. The fact that water is used for cooling means that these pieces of apparatus are subject to obstruction with scale. They should be cleaned just as the condenser is cleaned, whether they are of the double pipe or atmospheric type. The ammonia side of these parts of the system is not likely to become fouled as is the case with the condenser of the compression system, because the ammonia gases contain no oil. The same statement is true for expansion coils, but this does not mean that such parts are to be entirely ignored. Leaks are as likely to develop here as in the compression system and so these coils must be inspected for leaks just as must be those of the compression system.

As the function of the rectifier is to condense any water vapor that may be carried along with the ammonia gas, in order that it may perform its duty properly, it must be well drained. See that the rich liquor return drain to the generator is open and that the check valves function properly.

The purpose of the equalizer or exchanger in the absorption system is to cool the weak liquor leaving the generator and at the same time to heat the strong liquor going to the generator so as to relieve the load on that unit. There are occasions when it is found that besides performing this function it weakens the strong liquor and strengthens the weak liquor which is evidence of the fact that there is a leakage somewhere between the two liquids. This, of course, is to be avoided and when such a condition is thought to exist, the exchanger

should be carefully inspected and repaired if necessary. The cause of such an occurrence is usually a split or badly corroded inner pipe. In either case the defective tube should be drawn out and replaced by a new one.

Defective piping in the weak liquor cooler will allow the weak liquor to escape and mix with the cooling water where its presence may be detected by the odor of the waste water or, if the amount of leakage is small, by a Nessler's reagent test.

As the absorbing capacity of water for ammonia decreases as the temperature increases, the absorber, to operate correctly, should be as cold as possible and therefore should have an adequate supply of cooling water to carry away the heat generated by the formation of the solution. If of the atmospheric type, see that the distributing trough is level and that water is being spilled evenly along the whole length of the tube.

Although the mechanical power required in this system of refrigeration is nothing like the amount used in the compression system, a rich liquor pump being all that is needed, a failure of this pump may prove quite as serious as that of a compressor. Its function is to feed the generator and its failure may have the same effect on the plant operation as that of a boiler feed pump. For this reason such pumps are frequently installed in diplicate, one being maintained merely as a standby unit. This of course makes the stoppage of one pump a less serious matter, nevertheless it should be carefully examined while the plant is not in service for worn valve gear, rods, pistons, cylinders, etc. The same is true of the water and brine pumps used in the system.

Centrifugal pumps which are used quite extensively in the absorption plant for pumping liquids cause considerable trouble when the shaft becomes worn. The packing on a worn shaft is exceedingly short lived. In order to maintain a leak-proof stuffing box so that, in the case of a rich liquor pump, ammonia will not escape or air will not be drawn in, it is often necessary to renew the packing as often as once a month. Besides this, the gland is constantly in need of adjustment. Whenever the packing has to be renewed, it is necessary to stop and drain the pump which requires a considerable amount of time and means a direct loss in capacity. Is it not a much more satisfactory method of handling the situation to dress down the shaft when the plant is idle?

To overlook seemingly inconsequential defects in these units may cost a great deal later on when repairs cannot as conveniently be made.

Operation

In operating a compression type ice or refrigeration plant the engineer is probably more concerned with the compressor than with any other single piece of apparatus. Because this unit is constantly in motion and visibly putting forth effort, it receives, as a rule, more attention than any other unit and possibly justly so. It is probably as easily susceptible to disorganizing forces as other pieces of apparatus where the conditions which work for less efficiency are of a more insidious nature and are not as forcibly brought to the attention of the operator.

The important point in the operation of this unit is to be sure that the cylinder is handling the maximum possible amount of gas at each stroke. For this purpose indicator cards should be taken frequently and at regular set intervals. These cards should be examined carefully for evidence of faulty suction or discharge valve action, excess of clearance volume, and leakage.

Keep a careful account of the suction and discharge pressures and temperatures. Is the machine supposed to be run with slightly wet, dry or slightly superheated suction gas? A comparison of the temperature and pressure of the low pressure side will tell what the condition of the gas actually is. If it is not right, see that the condition is altered.

The quantity and quality of oil used for cylinder lubrication has an important bearing on the proper functioning of the plant. Enough must be used to prevent scoring of the cylinders, but when too much is used it simply passes over into the discharge line to befoul the piping and cause trouble generally. Use just enough and no more. Also use only the grade best adapted to your particular conditions. The oil should not be so volatile that it will vaporize at the discharge temperatures nor should it have a tendency to congeal or solidify at the lowest temperatures to be encountered in the system. Correct oil is absolutely essential.

Some oil is bound to get over in the discharge line and for this reason an oil trap is provided to collect as much as possible. In order that this piece of apparatus may function properly it must be well trapped, otherwise it might just as well not be there.

At least 50 per cent of all ammonia leaks that occur about the plant is at the stuffing box on the piston rod. See that the gland is turned up just enough to prevent the escape of the gas, but not enough to cause undue friction and heating on the rod. Make sure that the lantern is plentifully supplied with oil.

Maintain a careful watch on the head pressure, which, for best efficiency, should be kept as low as possible. High pressure indicates the presence of foul noncondensible gases; that the condenser tubes are dirty; that they are receiving an insufficient quantity of cooling water; that the cooling water is warmer than it should be; or that the system is under or overcharged with anhydrous. Ascertain the cause and make amends as soon as possible.

On the other hand operation at best efficiency demands that the suction pressure be kept as high as possible compatible with the work to be done. For ice-making the ammonia temperature should be maintained not more than 10 or 12 deg. below the brine temperature which in turn should be not more than the same amount below the temperature on the ice or 32 deg. F. A temperature of 8 to 12 deg. is about right, which corresponds to saturation pressure of about 22 to 25 lb. gage.

High overall plant efficiency depends upon efficient transfers of heat in each individual transmission. A condition which is capable of pulling down the overall efficiency as quickly as any other is poor brine circulation. Constant watch should be kept on the agitator to see that adequate circulation is provided at all times. For best results the brine should be kept strong so that its freezing point will be far below the temperatures ordinarily encountered. It is advisable to use calcium brine wherever possible but care should be taken to see that no magnesium chloride is mixed in with the calcium.

as it is precipitated by any leakage of ammonia from the coils and will cause trouble as any other sediment would.

In refrigeration rooms heat transmission is retarded by the formation of frost on the coils. This frost which may even form into ice under the right conditions should be removed at regular intervals. This operation is probably best performed by passing hot gas or brine (depending on whether direct expansion is used or not) through the coils for a few minutes until the frost is thawed loose from the pipe when it may readily be knocked off.

A condition conducive to good plant efficiency is regular and steady operation. In the ice plant cans should be pulled as soon as they are frozen solid and should not be allowed to remain in the tank simply because there is no immediate demand for them. Pull them at regular intervals and store. This storage reserve will come in handy in the event of an unexpected peak demand.

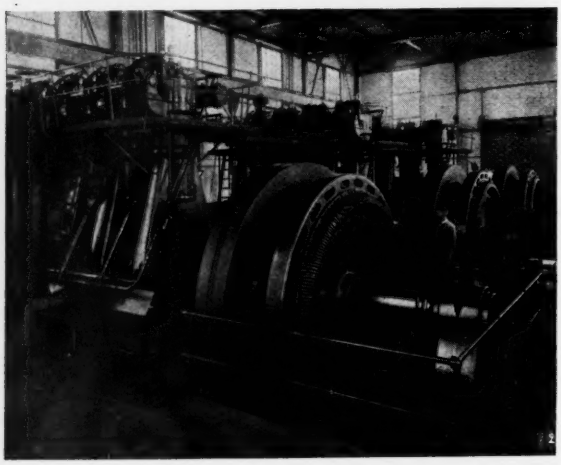
In pulling cans, they should be removed in rows across instead of along the coils so as to distribute the load as evenly as possible over the tank.

Keep the compressor running up to speed, 24 hr. a day, seven days a week, in order to obtain the best results.

Maintenance of Diesel Engines

SYSTEMATIC INSPECTION, CLEANING AND REPAIRING TO INSURE OPERATION. BY HARTE COOKE

FOR MAINTAINING a Diesel engine, the same general principles should be carried out as are used for the maintaining of any other equipment. When a machine is designed, certain objects are in view and the various details are arranged with the idea of accomplishing certain purposes and also with the idea that they will get adequate attention in operation and from time to time will have the proper things done to them to maintain them in good operating condition.



THREE 500-HP. OIL ENGINES IN A STATION UNDER REGULAR MAINTENANCE SCHEDULE

The time when these things should be done depends on two things. In general, after a certain time has elapsed inspection should be made to see whether attention is required and at intermediate times, if there is any indication of the improper functioning of any particular part, investigation should be made and such maintenance work as is necessary done.

For instance, with an automobile, to insure its regular operation, gasoline should be put in the tank from time to time, also water in the radiator and lubricating oil put in the engine crank case.

In addition to this, you are supposed at certain times to adjust the brakes, examine the tires to see if they need more air, look over the steering gear, timing, etc., to see that everything is in good condition. In the meanwhile, if any part shows need of attention it is given to it at once.

The same is true with a Diesel engine. In operation, the operator who comes on watch should see that his daily service fuel tank and the lubricators are filled, the lubricating equipment operating properly, also that all cylinders and the compressor have their proper supply of cooling water.

With any machine, the best results as to maintenance will be obtained if a systematic schedule of maintenance work is in use. For instance, with an automobile, if various parts are examined every so often or after so many miles, you will be more likely to keep the car in good operating condition than if you wait until some part shows signs of distress before it receives the attention it should.

MAINTENANCE LOG

WITH A Diesel engine, for proper maintenance a chart should be made up on which are listed all parts of the engine that require attention; that is, the exhaust valves, pistons, fuel valves, air intake valves, starting valves, piston pin boxes, crank boxes, main bearings, compressor valves, compressor pistons and lubricating equipment, and for each one of these items an estimate should be made as to how often it should be inspected and, if necessary, receive attention. On this maintenance log should be provided columns for each one of the cylinders and the compressor, so that on the log can be noted just the date on which each one of these parts was inspected and a note can be made as to its condition. If any overhauling is necessary, it should be done at these times.

Everything about the engine, and, in fact, about the whole station should be enumerated on this schedule, no matter how infrequently it may require attention. Then, at a certain time period determined, each one of these things should receive proper inspection and if necessary, such maintenance work as is necessary should be done. In general, for any machine to be kept in first class operating condition all parts should be inspected at least once a year even though maintenance work may not be required.

Frequency and Details of Inspection

After the parts have been inspected once or twice, it can readily be determined whether, under the particular conditions that exist in this station, the period might be modified. Maybe the time periods can be made twice as long and for some of the parts the time periods may need to be shortened.

In general, for a Diesel engine the exhaust valves should be examined at intervals of about three months. The best way to care for the exhaust valves is to take out the exhaust valve cage, and put the spare valve cage in its place. When the spare cage is put in and drawn down on the gasket, the cam roller clearance will have to be checked up, as the gasket may compress somewhat, or if a new gasket is put in, it will not compress to the exact thickness of the old one, and this will change the cam roller clearance, so that adjustment should be made to take care of this. Then, as soon as convenient, the valve which has been removed should be taken apart, such maintenance work as is necessary can be done, and everything put in the proper order. Later, another exhaust valve cage can be removed, the valve and cage which have been fitted up put in its place, and the process repeated indefinitely.

The pistons should be drawn for examination about once a year, and other parts inspected at intermediate intervals. When the pistons are drawn for examination, the piston rings should be removed. If any of them are stuck, they should first be soaked in kerosene, and if care is used they can usually be removed without breaking. If, however, one is found which is stuck solid, it has to be broken to be removed, so that the groove can be cleaned out. The whole piston should be cleaned up and examined to see how it is wearing, the piston pin removed and examined, and the boxes on the piston pin end of the connecting rod adjusted to the proper standard clearance; the piston pin can then be put back in place, and made secure.

Fuel valves should be taken out every 2 or 3 mo., as in many cases a great deal of dirt is brought into them by blast air. They should be taken apart, and thoroughly cleaned.

Air intake valves do not require much attention, but it is a good plan to remove them about once in 6 mo. for examination, when such refitting as is necessary can be done.

Attention required by the compressor valves depends a great deal on the care that is taken to give the compressors no excess of lubricating oil, and also to prevent dust from getting into the compressor.

When the compressor is new, and it is not known what the effect of operating conditions may be, it is a good plan to take these valves out in the course of a couple of weeks, examine them, and clean them, if necessary. If practically no cleaning is required, the interval may be extended next time to a month, and the next one to say, 3 mo. In general, it is a good plan to examine these valves once in 3 mo.

Little Things Need Attention

It should be remembered that for the proper maintenance, it is not always the big things that need attention, but all the various details should be looked into, and given proper attention, such as the lubricating oil pipe, which about every 4 to 6 mo. should be disconnected, blown out with air and washed out with kerosene to remove any accumulation which may have lodged in the pipes. It is well at these times also to wash out the inside of the engine frame, and clean out all the accumulation from the base.

Now with an automobile, maintained in the best condition, you may be unfortunate enough some day to discover that a tire has gone flat, and maintenance work of course is required at once; likewise with a Diesel engine, something may come up from time to time which will cause improper functioning of some of the parts, and in such case of course, the maintenance work necessary should be done then and there. The illustration shows a station maintained by schedule, whose record for continuous performance has been remarkable.

Requirements of Lubricating Oil for Diesel Engines

FOR PRACTICAL reasons it is desirable to use the same oil for all parts of an engine—cylinders and bearings. Of course, no operator would be so "penny-wise and pound foolish" as to jeopardize the life of an engine costing nearly $100 per horsepower by using an oil not known to be well refined and of the first quality. Unfortunately, the degree of refining cannot well be judged by those who operate engines, and they must accordingly rely on the reputation of the refiner for this. In addition, the requirements which an oil must possess, as given in an article in Lubrication published by the Texas Co., are as follows:

1. The oil must, of course, not congeal at any temperature to which it will be exposed in service.

2. The oil must be viscous enough to form a fair piston seal, but not so viscous as to cause undue fluid friction in the bearings.

3. It must spread readily over the cylinder walls, and not remain in streaks or patches.

4. It must not form bad emulsions as it is frequently mixed inadvertently with a little water in service, sometimes even salt-water.

5. When exposed to the intense heat of combustion, which will decompose any oil, it must leave a minimum of carbon when disintegrated, and the carbon must not be gummy.

6. It must not be so volatile that an undue quantity will be necessary to maintain a good film on the cylinder walls.

7. It must not react and thicken with sulphur from the fuel.

Several of these items are conflicting. For example, the conditions in a two-cycle engine are particularly bad for cylinder lubrication, because the oil is not only more frequently subjected to heat, but the velocity of the burned gases at the exhaust ports greatly increases the evaporation of oil from this part of the cylinder. A less volatile oil can be secured only at the expense of higher "carbon residue" and higher "cold test." The choice of the best oil to use is thus, as in other branches of engineering, a compromise in which the judgment of the specialist must be resorted to as to which particular items enumerated above must be given the greatest weight.

The Plant Operator's Job

ITS IMPORTANCE AS APPLIED TO MEDIUM SIZED AND SMALL POWER PLANTS. BY A. T. HUNT

IN LARGE stations supplying public utilities, the electrical and steam equipments are handled by different operators, each a specialist in his field. The successful operation of the individual units in the stations and of one station with others on the same system can be met only by having the entire detailed operation of the system under the direction of a single head known as "Load Dispatcher," whose duties require a complete knowledge of the various demands upon the system as well as the capacities and peculiarities of the generators and switching apparatus supplying it. The operator at the power house, therefore, has little general discretion and handles the machines and switching apparatus only upon orders from his "Load Dispatcher."

Medium sized and small power plants may be conveniently divided into two classes, viz., public utility plants and industrial power plants. In both of these groups the operator's position is relatively more important, since he is called upon to assume at least some of the duties of the load dispatcher, and handles the switchboard and often the steam end of the generating equipment as well. Strange as it may seem, therefore, the smaller plants actually require a higher grade of men for station operators than do the immense public utility plants; and these medium and small sized stations present exceptional opportunities for gaining general power plant experience necessary for advancement along power plant engineering lines. The remarks in this article are primarily for the operators of these medium and smaller sized public utility and industrial plants.

The duties of the operator for the electrical end of such a plant may be summarized about as follows:

(1) General operation of the switches, and rheostats for the electric generators, exciters and feeders pertaining to the system under his control;
(2) Keeping a log of the operation of the plant and taking care of graphic records of charts pertaining thereto;
(3) Minor maintenance of the switchboard equipment;
(4) Care and attendance of the electric end of the generators, exciters, etc.

PLANT FAMILIARITY

FIRST AND foremost, it is the duty of the operator to become acquainted with the plant and the system it serves. Every single detail of the generator, exciter and switchboard equipment, as well as piping, and valving arrangement, must be known to him, and their functions clearly understood. The importance of this knowledge may not be over-rated, if the operator is to fulfill the ultimate of his duties. Not only should he be well acquainted and thoroughly familiar with all of the details of his own station, but he should be equally familiar with the details of every other station or system to which his station may be electrically connected. No feature is too small to be overlooked. Every detail in the plant, if the engineering of the plant has been properly carried out, has been given proper consideration as to its location and suitability, and the operator should recognize its importance and know its use. He must not only be acquainted with all of these things, but he should be ultra-friendly with them; i. e., he must know the limitations of each item of the equipment, such as heat limits of bearings of generators, their windings, conductors, features of and the normal overload limits of the switches, meters, and the like. Such an intimate knowledge of the various items of the equipment certainly is not complete without a good knowledge of the fundamental principles governing the operation of each of the various items of the equipment, which knowledge is necessary to undertake the minor maintenance and adjustments of the moving parts. Manufacturers' instruction books, diagrams, drawings, pictures and literature can be readily obtained and a complete file of such literature should be kept in a neat case in the power house for study and reference, although comparatively few power houses are today thus completely equipped.

KEEPING RECORDS

ONE OFTEN hears a word of complaint from operators in various power plants concerning the necessity of keeping what they consider voluminous records of operation. The man at the board ofttimes has really only a hazy idea of this quite important side of his work. A text might be set up for this feature of his work: WHAT IS WORTH DOING AT ALL IS WORTH DOING WELL.

Therefore, if there is need of keeping any records whatsoever, they should be well kept. They should be uniform, neat and legible and above all should be complete, containing continuous and complete data on the operation of the plant. Complete records of the operation of all the variable factors of a plant enable a wide-awake operator to readjust quickly the equipment under his control so as to conform to the various conditions of loads and obtain the best economy in operation. Every operator should know the combination of machine in his plant which will carry any given load with the highest all around economy and he should be quick to set up that combination corresponding to the fluctuation of the load. Such complete record also furnishes indications of unusual conditions of the equipment which, if not kept in mind and attended to at the proper time, may result in breakdown, expensive delays, and possibly actual destruction of much valuable machinery.

In this connection it may be emphasized that, if all the variable factors affecting the operation of electric machinery are noted in the log, it is conclusive evidence that the operator observed these factors at the times stated in the log, and in case of an unexpected interruption to service or loss of machinery the operator is in a strong position in respect to his share of responsibility in connection with such accidents.

There are still other important uses for the complete log. It supplies the management with the necessary information regarding the variations in the load and when, as happens in practically all power houses, the question of extensions, improvements and rehabilitation is up for discussion, a knowledge of the past performance of

the plant, as shown by the complete records of operation for years back, is of the greatest importance. From every standpoint, therefore, the operator should realize the importance, not only to himself, but to his company, of maintaining at all times his complete records of operation.

What has been stated above regarding the importance of the log applies equally well to graphic charts of the various curve drawing instruments. It is a discouraging sight to see, in many power houses, perfectly good graphic instruments out of operation and to learn the really trivial reasons for such condition, such as, "The ink ran dry," and "We need more paper," and worst of all, "Well, the record is about the same every day." If long familiarity proves that the record is the same every day and the management indicates that the records are of no value, certainly the instruments should be disposed of while yet they have a fairly good second-hand value. The chances are, however, that the instruments have a real economic value in that plant. Experienced power plant men are quick to appraise an operator's character from the condition of his plant records.

Care of Apparatus

Every operator should be capable of correcting minor defects in his switchboard equipment. Defects in the instruments require expert attention and in general it may be said that the majority of operators do not have this experience, and therefore should not undertake the correction and adjustment of instruments. The operator will, however, be called upon to clean and maintain the switches, circuit breakers, etc., He should always keep on hand an adequate supply of fuses of proper sizes, and indicating lamps where required. It seems almost unnecessary to make such a statement, but our experience is that often such minor details are neglected with resulting inconvenience and possibly delay to the system.

Meeting Emergencies

Engrossed in the more or less routine duties of keeping log, fixing up the place, etc., one of the most important features of power plant operation is likely to be overlooked and so neglected. It is the feature usually requiring the exercise of all of the acquired technical knowledge of the operator and often his success with respect to this feature depends upon his level headedness. This is the ever possible but usually infrequent feature of emergencies. In the order of their importance they are: accident to human life, fire failures of switchboard and generator equipment, and outside line trouble.

Protection against accidents and preservation of human life is of the greatest importance. The operator in most plants today must be very careful, and his bump of caution must be cultivated. Disregard of precautions has cost many lives, caused much suffering, and no one knows where the lightning will strike next. He has the fatherly duty of supervising the work of less skilled mechanics in their duties near the switching and generating equipment to protect them from injury.

At least two men on every shift in every power house should be trained as "first aiders." In case the management has not already arranged for it, the operator should insist upon and obtain conferences with the company's doctors and learn by practical demonstration; first, by the doctor on the operator, then, by the operator on the doctor, and then by operators one upon another, how to induce artificial respiration and the subsequent treatment for shock; also, the procedure for treating burns; and every power plant should have a first aid kit kept fully equipped. Without exception, every operator in every power house should be thoroughly acquainted with first aid measures. It is not enough that printed directions are already mounted on the walls to be read and cogitated over, after an accident has happened.

Switchboard and generator failures are usually complex and generally sudden. It is at such times that the operator will demonstrate whether or not he has become ultra-friendly with his equipment in all its details. His success with this emergency will depend on the thought and study he has previously given to the procedure to be followed for each kind of trouble which he can imagine would be liable to occur. Three features are of importance: Protection of life; minimum interruption of service; and protection of equipment against damage. Every effect has its cause or causes. If the operator is always alert in detecting causes and remedying little defects when found, it is safe to say that failures will be infrequent in his plant.

State it as a conundrum: "When is a failure not a failure?" Answer: "When there is a good operator." Clean equipment, properly oiled, regularly inspected, with defects corrected when first noticed, is extremely reliable. Abuse and neglect, not use, cause most of the failures. It is to the credit of the operating fraternity as a whole that the percentage of failures is low, but new men are constantly being recruited who do not have the training and experience, and the importance of this feature must be emphasized often.

Outside line troubles is annoying, but usually is of minor importance. Strict rules are usually in force relative to procedure in such cases, all of which must be familiar to the operator. Here again the life hazard is an important factor, usually conflicting with considerations of service. The one operating feature of importance is alertness and speed in carrying out the rules pertaining to the interruption. In case no definite set of rules is in force, the operator should insist on their issuance by the superintendent for his own guidance, as well as for the protection of life and property of the public and of his company.

The knowledge of the manual of starting and stopping generators and exciters, opening and closing switches in their proper order and at the right moments, necessary and important though it is, does not represent the complete requirements for an operator in the average power house today. These are only his routine duties, which, after some weeks and months, become almost automatic. His peculiar relation to the equipment of the plant requires that he also give to his job his most thoughtful attention and study. He is the custodian of the equipment during his working hours. He must, therefore, be able to handle any situation which may arise. Can he feel sure of acquiting himself with credit? He can if his preparation has been thorough, if he has become "ultra-friendly" with his plant and has studied and mastered the possibilities and peculiarities of his equipment.

Generators

Care and Operation; Methods of Detecting and Correcting Trouble

THE DEPENDENCE of modern manufacturing operations upon the continuous operation of the electric generator in the power plant is too well appreciated to require discussion here. Practically all operations in industrial plants are dependent, either directly or indirectly, upon the supply of electrical energy from the generators and it may be truly said that when the generator stops, the plant stops.

Generators, in common with all other machinery, are subject to failure. While such failures may be due to purely mechanical conditions, such as may occur in any

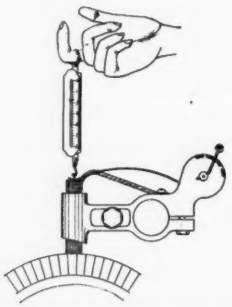


FIG. 1. SHOWING APPLICATION OF SMALL SCALE IN DETERMINATION OF BRUSH PRESSURE

type of machine, they may in addition be the result of abnormal electrical, magnetic or thermal conditions. The operation of these machines must, therefore, be carefully watched and the ability of the operator to detect improper conditions in their early stages will often effect monetary savings of considerable magnitude in a timely application of preventive measures.

Daily Care

EXCESSIVE HEATING is one of the principal causes of generator failure and is one of the foremost conditions to be guarded against. In small machines, the temperatures are easily determined by feeling with the hand or by means of thermometers applied to the hottest accessible part. The actual temperature in this case is estimated by adding a correction factor of 15 deg. C. except where the instrument is applied directly to the surface of the bare winding, in which case but 5 deg. C. need be added.

Heating may result from any of a number of conditions and may localize in the armature, the field coils, the commutator or the bearings. If not checked, however, heat from any of these parts may spread to other parts of the machine. A machine should be watched closely during the first hour or two after starting, for if any faults are present, it is during that time that they will make themselves manifest. The field coils can generally be tested for heating by placing the hand on them. To determine whether the armature is running hot, if no instruments are installed for this purpose, place the hand in the current of air thrown out from it by centrifugal force.

The most common and also, perhaps, the most obvious cause of overheating is overloading. No machine must ever be overloaded except for short periods of time and then only in accordance with the manufacturer's instructions or in accordance with the standards set forth by the A. I. E. E. There does not, however, appear to be any advantage in operating at lower temperatures than the safe limit, so far as the life of the insulation is concerned.

Cleanliness in the operation of generators is a requirement which ranks second to none in importance. Dust, especially metal dust, should never be allowed to accumulate on any part of the machine. If conditions are such that dust cannot be kept away from the machine, provision should be made for blowing out the windings occasionally with compressed air. An outlet on the air system provided with a short length of flexible hose will enable the attendant to reach any part of the winding. A comparatively low pressure, say about 25 to 50 lb. per sq. in., should be employed for this purpose as a higher pressure is liable to damage the insulation. Before directing the air into the windings the

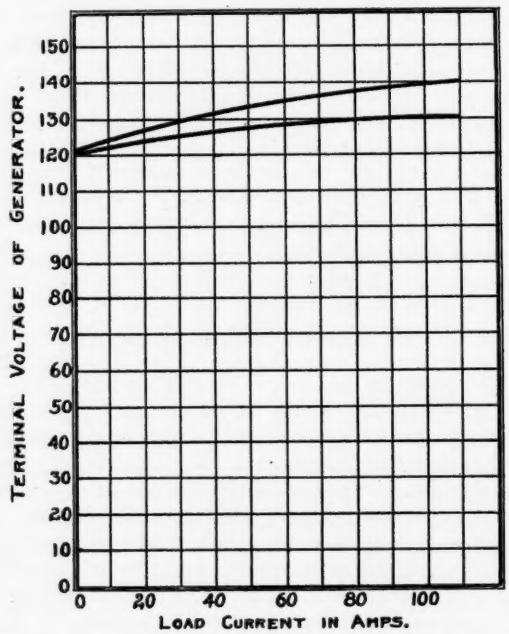


FIG. 2. VOLTAGE CHARACTERISTICS OF TWO COMPOUND GENERATORS

operator should first take care to blow out any water which may have accumulated inside the air line.

On direct current machinery the commutator and the collector rings on alternating current machinery should be given particular attention and should always be kept clean, smooth and true. Oil must be kept away from the mica end rings of the commutator as oily mica will soon burn out and ground the armature. It is essential also that the commutator be kept cool; an overheated commutator will decompose the carbon brushes

and cover the surface of the copper with a black film. If this should occur through negligence, it must be remedied immediately by thoroughly cleaning the commutator and brushes and refitting them carefully so as to make good contact. It may be necessary to substitute a different kind of carbon brush.

A commutator under proper operating conditions will acquire a mahogany colored glaze on its surface and needs no further attention except a daily wiping with a clean piece of canvas or cloth free from lint. When shutting down a dynamo, as the speed falls quite under normal, if a kerosene-soaked piece of lintless cloth is wiped over the commutator which is then at once wiped with a clean lintless dry cloth, all accumulated gum is removed from both the commutator and the brushes.

Brush pressure upon the commutator should not exceed 5 lb. per sq. in. Generally tensions of 2.5 to 3.5 lb. per sq. in. are used on commutators and 3 to 5 lb. per sq. in. on the slip rings of alternating current machinery. An experienced operator can frequently determine the tension or pressure with which the brush bears against the commutator by slightly raising the brush in the brush holder. For the inexperienced man, however, it is preferable to test the brush tension by means of a small spring scale in the manner indicated in Fig. 1. In making these determinations, care should be exercised to see that the brushes work freely in their holders.

Opposite brushes should be offset so as to bear upon different parts of the commutator, to prevent wearing a groove in the latter. As far as possible, the entire surface of the commutator should be rubbed by brushes.

Bearings should receive frequent attention to see that the oil supply is maintained properly and that the oil rings do not stick. They must be kept free from dust and grit. Oil wells should be filled to such a height that the rings will carry sufficient oil upon the shaft. If the bearings are too full, oil will be thrown out along the shaft.

In case a machine has just been started, the bearings must be watched carefully until they have become warm. The oil level may rise considerably during the warming interval because of expansion by heat.

All electrical connections should be examined from time to time to make certain that none of them have become loosened due to vibration or other cause. An apparently perfect mechanical connection may often be a very poor electrical connection and may cause excessive local heating. It is a good plan to test the efficiency of all the electrical connections occasionally by measuring the drop across them with a portable voltmeter.

When the generator is in operation all bolts and other mechanical connections should be maintained perfectly tight. A loose belt working itself out and being drawn into the machine by the magnetic field may wreck the machine and cause injury to the attendants nearby. For the same reason, all tools, small pieces of iron, etc., should be kept away when the generator is running.

Lubrication

Two parts of a generator require lubrication: first, the bearings, and second, the brushes. The lubrication requirements of generator bearings do not differ materially from those of other bearings; the oil used must be selected to suit conditions of size, speed, pressure, temperature and mechanical condition. Where the bearings are small, the shaft speed high, where the pressure and temperature is low and where the mechanical conditions are good, a light bodied quick acting oil must be used. Heavy-bodied oils possessing "sticktion" must be employed where the bearings are large, the shaft speed low and where pressures or temperatures are high. High speed shafts are those running over 300 r.p.m. Since most generators operate at a speed of 300 r.p.m. or over it will usually be best to use a light-bodied oil.

Normal operating temperature in generator bearings should not exceed 140 deg. F. Whenever this temperature is exceeded the cause should be investigated.

On turbo-generators, where circulating oil systems are used the temperature of the oil returning from the bearings should not be more than 130 deg. If the temperature runs higher, it indicates insufficient cooling capacity. Where the main bearings are water cooled, the temperatures are lowered by about 10 deg. F.

Oil in ring oiled or other reservoir type of bearings must be renewed at least every 6 mo. New oil from the barrels in which it was delivered should always be poured through a strainer into the oil can, to avoid chips of wood and other impurities getting into the bearings.

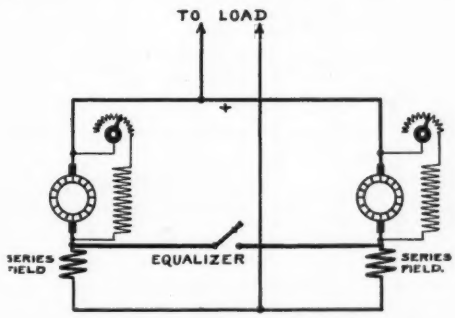


FIG. 3. DIAGRAM SHOWING EQUALIZER CONNECTION BETWEEN TWO COMPOUND GENERATORS

When bearings on small generators heat up, they are usually easy to cool down, as the total amount of heat present in the bearing is relatively small. Generally a liberal supply of the oil in use is all that is required. If the bearings are heated to such an extent that they have been distorted or that the white metal has started to flow, the unit will have to be shut down and the bearings overhauled.

When the bearings on large machines heat up, the case is different. The first thing to do is to increase the bearing clearance by slacking back the brasses. If the bearing has not seized but is extremely hot, it is usually sufficient to feed into it a liberal supply of steam cylinder oil (which possesses superior lubricating qualities under high temperature) until the bearing cools.

It is also a good plan in case of a hot bearing to reduce the speed immediately. Do not bring the machine to a dead stop, however, as this might cause the bearing to "freeze."

Lubrication of Brushes

Brushes, as a rule, do not require much lubrication. It is often recommended to boil carbon brushes in refined paraffin wax, but a trace of vaseline applied to the commutator is generally equally satisfactory. Graph-

ite or graphitized carbon brushes are self-lubricating and as a consequence need no other lubricant. Graphitized carbon brushes will operate successfully at any angle and will give satisfactory results for most commercial applications. Oil should never be applied to the commutator on which graphitized brushes are used on account of the formation of smut on the commutator surface, which causes poor commutation.

In case it is necessary to use non-lubricating brushes it is good practice to equip the machine with alternate sets of self-lubricating and non-lubricating brushes, the latter depending upon the former to supply whatever lubrication is needed.

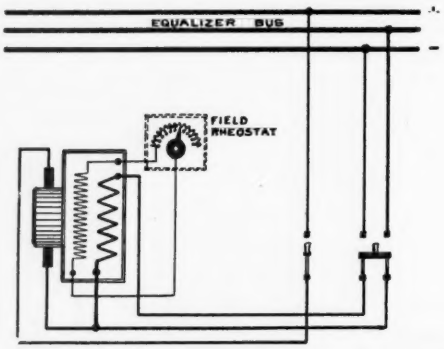


FIG. 4. THIS ARRANGEMENT PRECLUDES THE POSSIBILITY OF EQUALIZING SWITCH BEING LEFT OPEN

The brushes used on alternating current slip rings should be as nearly self lubricating as possible and should not wear or cut the rings.

Parallel Operation

In order that two direct current generators may operate properly when connected in parallel it is necessary that they possess similar characteristics and, in the case of compound wound generators, that they be provided with an equalizer connection. If the voltage characteristics are dissimilar, as for instance the two curves shown in Fig. 2, it may be concluded that the machines will not operate in parallel, even with an equalizer connection, for although at no load they have the same terminal voltage, they do not undergo a similar variation of voltages as the loads increase.

The purpose of the equalizer is to connect the series fields of two or more compound generators in such a manner, that if the voltage of one machine falls, the series field of that machine will be strengthened immediately by current from the other machines, thus re-establishing the normal voltage. Any tendency for the increased voltage of one machine to reverse the direction of current through the series field of another machine is prevented by the proportional dividing of currents through the field coils of the generators. The equalizer consists of a conductor joining the points of connection between the armature and series field of each machine as shown in Fig. 3, thus putting the series fields of the various machines in parallel with each other.

In the operation of compound generators in parallel, each machine must be adjusted separately to give the same degree of compounding by means of a German silver shunt connected in parallel with the series field.

If the generators are flat compounded, they may be connected to the circuit by means of triple-pole switches. When the machines are over-compounded, however, it is difficult to parallel them unless separate equalizing switches are provided. Three single-pole switches are, therefore, often used, but this practice is open to the objection that if the equalizing switch should accidentally be left open, serious trouble might occur. To make certain that the equalizing switches are closed, therefore, the method of connection shown in Fig. 4 is often used in which a double-pole and a single-pole switch are used.

In a three-wire system where two generators are used in series, it is necessary to use two equalizers if it is desired to parallel two compound sets. The method of connection is shown in Fig. 5. The load on either side of the system will compound its generators independently of the other side, as each has its own series field. Thus proper voltage will be maintained even though the load is unbalanced.

Equalizer Operation

Where compound generators are arranged for parallel operation with 3 single-pole switches the method of procedure employed in putting a machine on the line is as follows: Assuming that the equalizer switches on all machines already on the line are closed, the incoming generator is first brought up to its rated speed, and the voltage adjusted by means of the field rheostat to a value a trifle higher than the line voltage. This may be ascertained either by employing a differential voltmeter which indicates directly the difference in voltage between the line and the incoming machine or by means of a single voltmeter connected through a quick-acting double-throw switch first to one side and then to the

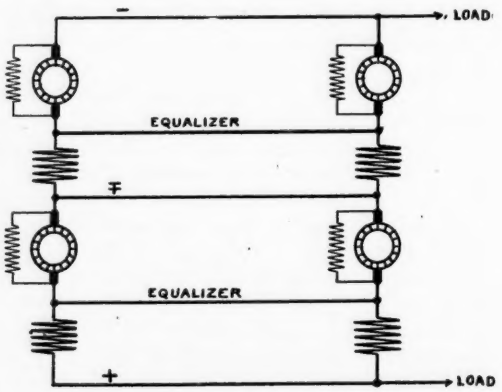


FIG. 5. PROPER CONNECTIONS FOR PARALLEL OPERATION OF COMPOUND GENERATORS ON A 3-WIRE SYSTEM

other. The voltage of the incoming generator having been properly adjusted, the switches are closed in the following sequence; first, the equalizer switch, second the switch connected to the series field side of the machine, and third, the one connected to the armature side.

In case a three-pole switch is employed, the voltage of the incoming generator is first adjusted to a value a trifle below line voltage. This is necessary because of the fact that when the three-pole switch is closed, the current immediately flows through the series field winding, thus increasing the excitation of the machine and causing a rise in generated voltage.

When the machines are fully connected to the line, the voltage of compound generators is adjusted in the same manner as for shunt generators, i. e., by manipulation of the field rheostat.

In disconnecting, the current shown by the ammeter is reduced to a small value by cutting resistance into the field rheostat; then open the main switch. In this manner, the switch blades will not be injured by arcing, and the line voltage will not be disturbed.

Sparking—Its Causes and Remedies

Excessive sparking at the commutator is one of the most serious and perhaps the most persistent difficulty encountered in operating direct current electrical machinery, and due to the multitude of causes from which it may arise, is often difficult to eliminate. While a moderate amount of sparking is not objectionable, the detrimental effects are cumulative and in time may lead to serious trouble.

If sparking is allowed to continue in a machine, the effects will be made manifest in a burning and gradual roughening of the commutator, as well as pronounced local heating. Roughening of the commutator surface in this manner, of course, only serves to increase the violence of the sparking until finally it will so damage the machine as to make it necessary to shut down.

As stated above, causes of sparking are numerous and it is often due to a combination of conditions, or to conditions external to the machine itself. The most common conditions to which sparking is due, are fairly well understood, and in many cases sparking is only the result of negligence on the part of the attendants. Among the more common conditions conducive to sparking may be enumerated the following:

(1) Overload; (2) Sudden changes in load; (3) Incorrect position of brushes, i. e., not set in exact neutral

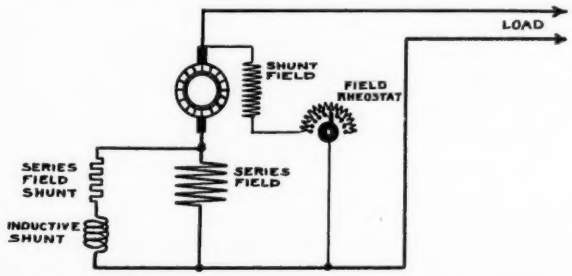


FIG. 6. DIAGRAM SHOWING INDUCTIVE SHUNT IN SERIES WITH SERIES FIELD SHUNT

plane; (4) Unequal spacing of brushes; (5) Brushes not fitted exactly to the commutator; (6) Improper kind of brushes used; (7) Rough or pitted commutator; (8) Loose commutator bars; (9) High mica; (10) Insufficient brush pressure; (11) Oil or dust on the commutator; (12) Weak magnetic field; (13) Vibration of machine or ground; (14) Broken circuit or ground in the armature.

Sparking due to overload, of course, is too obvious to require much discussion. Overload is an abnormal condition which subjects both the commutator bars and the brushes, as well as practically all other current carrying parts of the machine, to a higher current density than that for which they are designed and sparking is only one of the difficulties encountered under such conditions.

Often when one generator furnishes current to a number of different appliances, there will be one or more large machines which are stopped and started frequently. This causes sudden changes in the output of the generator. As a result of such changes, unless special precautions have been taken, and provided the machine is fitted with an ordinary non-inductive series field shunt, the self inductance of the field winding will force more than a proportionate amount of current through the shunt during the sudden increase in load. Conversely, it will also retain more than a proportionate

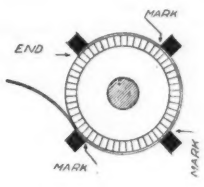


FIG. 7

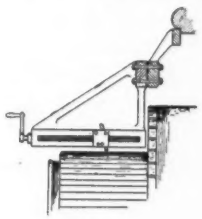


FIG. 8

FIG. 7. SHOWING USE OF A STRIP OF PAPER IN THE PROPER SPACING OF BRUSHES AROUND COMMUTATOR

FIG. 8. TOOL HOLDER USED IN TURNING OFF COMMUTATOR ATTACHED TO BRUSH HOLDER RING

share of load current during a period of decrease. This unequal rate of change of current in the shunt and series field will cause distortion of the field magnetism, which may result in serious sparking.

While, in many cases, sparking under these conditions would not occur often enough to produce serious effects, it can, if necessary, be eliminated satisfactorily by including an inductive element in series with the series-field shunt. Such an arrangement is shown in Fig. 6. The inductive element may be made of copper wire wound around an iron core having an air gap that is capable of being adjusted to give the requisite amount of self inductance. The total resistance of the inductive and non-inductive elements in series must be such as to give the degree of compounding necessary for steady currents. The resistance of the inductive portion alone must be adjusted by trial to give sparkless commutation when the load is suddenly varied.

Sparking due to the brushes not being set at the neutral point may be tested by shifting the brushes back and forth on the commutator. The condition is easily remedied by shifting the brushes in the above manner until sparking is reduced to a minimum.

Proper and sparkless operation of dynamos furthermore requires equal spacing of the brushes. If improperly spaced, they may be adjusted as follows: take a piece of paper several inches wide and of the same length as the circumference of the commutator and measure and mark it into the same number of equal spaces as there are brush holders. Then by placing the paper around the commutator under the brushes as indicated in Fig. 7 and shifting the brush arms so that the toe or heel of each set of brushes will come to its respective mark on the paper, the brushes are equally spaced.

The brushes must be carefully fitted to the commutator. This may be accomplished by drawing a strip

of sandpaper between them and the commutator or by pasting an endless band of sandpaper around the commutator and then slowly revolving the armature by hand or power.

Another requirement essential to obtaining sparkless commutation is the selection of the proper kind of brushes to conform to the needs of operating conditions. The brush should be homogeneous and the current density in the brush tip should not become excessive. For undercut commutators, the brush material should be entirely, or nearly, free of abrasive material or the commutator will wear unduly fast. For smooth commutators with soft mica the brushes should be highly abrasive.

If the sparking is caused by a rough or pitted commutator, the obvious remedy is to bring the commutator back to its original smooth condition. If this roughness

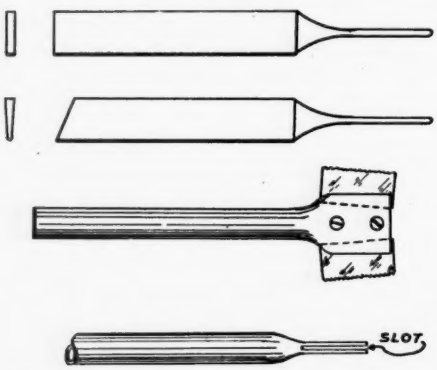


FIG. 9. TOOLS FOR USE IN SLOTTING COMMUTATORS

or pitting is moderate, the commutator may be smoothed with a sandstone or with sandpaper applied by means of a wood block. Emery cloth or paper should never be used for this purpose and even when using sandpaper, the brushes should always be raised in order to prevent particles of sand becoming imbedded in the brush faces. In cases where it is necessary that the machine be driven under its own power when surfacing is being done, as few brushes as will serve to carry the current into the armature should be left down. Ordinarily, half of the brushes on two adjacent arms is sufficient. This permits grinding half of the face of the commutator at a time, leaving the brushes down only on that part of the commutator where the stone is not working.

Should the pitting or roughness of the commutator be so serious that surfacing in the manner described in the foregoing proves ineffective, the commutator should be turned down, either by mounting the armature in a lathe or by means of the tool rest attachment, shown in Fig. 8, usually provided with large machines.

Turning down, however, should not be done unless absolutely necessary for with each turning down an average of 2 to 3 yr. of its useful life is lost.

The sparking difficulty due to a loose commutator bar may often be corrected by tightening up the clamp ring which holds the segments in place and then smoothing off with a stone.

When excessive sparking is accompanied by a drop in the generated voltage of the machine, or in the case of a shunt motor by an increase in speed, it may be concluded that a weakening of the magnetic field is the cause of the trouble. This is due to the relatively strong distorting effect of the armature reaction, causing the plane of commutation to be shifted considerably from its normal position. Such a weakening of the field may be the result of any of several conditions. It may be caused by a short circuit of a portion of the field windings, by a broken circuit, by a reversed connection in one of the field coils, etc. If such faults are external to the winding, they may be easily repaired; but if the fault is not readily accessible, rewinding will be necessary.

PITTED MICA

PITTED MICA is a term applied to a serious type of commutator trouble usually encountered in cases where the commutator has become oil soaked, due to leaking or over full bearings.

Mica readily absorbs oil. If, therefore, oil remains upon the surface of the commutator for any length of time, a certain amount of this oil will soak into the mica segments between the bars. This will result in arcing and ring fire, causing the mica to be burned away, and leaving carbonized paths sometimes 2 or 3 in. in depth. If this condition is noticed in its early stages, before the pitting has reached a depth of, say, ½ in., the commutator may be temporarily repaired by patching or filling. This may be done as follows: Cut away all of the carbonized mica carefully and remove all burnt particles with a knife or a thin hack saw blade. After having thoroughly cleaned the holes in this manner, fill them with a good commutator paste of which there are many upon the market. If none can be secured, however, a good filling paste may be made up as follows: Two parts plaster of Paris; one part powdered mica; and enough glue to make a thick paste. This, when applied, will dry quickly and when kept free from oil will hold for a year or longer.

It often occurs that the mica segments have been burned by excessive sparking, such burning not necessarily having been superinduced by oil and that the pitting is confined more or less to the surface. In such cases, the trouble is readily eliminated by undercutting. This procedure, which is the same as that used to relieve the trouble known as high mica, consists in slightly grooving the mica below the surface of the commutator. The depth to which the insulation may be grooved depends upon the thickness of the mica and the voltage normally existing between adjacent bars. For usual thicknesses and with the voltage between segments ranging between 10 and 18 v., undercutting should not exceed 1/32 in. It may be done with a hack saw or preferably with tools specially made for the purpose illustrated in Fig. 9.

BEARINGS

UNDER NORMAL conditions the wear on generator bearings, especially in installations where forced feed lubrication is used is negligible. It is only when abnormal conditions prevail, when grit enters a bearing for instance, that excessive wear takes place and unless such abnormal conditions are removed at once, failure of the bearings becomes imminent. Any case of excessive heating of bearings must, therefore, always receive immediate attention and the cause be removed.

The most common causes of worn bearings may be enumerated as follows: lack of oil; rough or cut shaft; foreign matter in bearings; bent shaft or misalinement of bearings; unequal distribution of air gap between armature and field poles; excessive side strain due to a tight pulley; sticking of the oil rings; and thrust due to improper leveling.

Armature Repairs

Armature coils are liable to three main types of faults, namely, short circuits, open circuits and grounds. In a new armature or one just rewound there may also exist in rare instances trouble due to improper connections such as reversed coils.

Repairing of these faults after their exact location has been ascertained may be simple, but often, on account of the cramped quarters for working, the task is quite difficult.

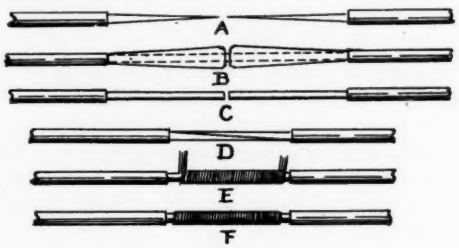


FIG. 10. STEPS IN SPLICING ARMATURE CONDUCTORS

In the case of a short circuit, the offending conductors must be separated and the faulty spots taped, silk tape being employed where space is limited. Occasionally a satisfactory repair may be effected by merely inserting pieces of mica between the conductors and then tying them together with tape or cord.

An open circuit is more or less difficult of repair depending upon the nature and location of the fault. If the wires are merely loose from the commutator necks, or are broken off in an accessible position, the remedy is readily applied. A small sleeve soldered on will make a neat and lasting splice, although sometimes it is easier to make a common twisted joint.

It is necessary under certain conditions to make a splice in a portion of a conductor lying in a slot. To do this properly, first remove the band wires and slot sticks and raise the conductors out of the slot containing the damaged wire. If it is a bottom coil that is damaged, it will be necessary to raise enough upper coils to free the faulty side. Care in doing this may save hours of needless work afterwards. When the open ends are located, they must be separated from the remaining turns of the coil as much as possible, without damaging the insulation. The ends are then flattened into a wedge shape by being hammered against a smooth iron block. Figure 10 illustrates the various steps in making a splice. A shows the conductor flattened out. The extra width is trimmed off along the dotted lines as in B. The ends are now tinned and soldered as shown at D. The joint is completed by winding with fine conductors as shown at E and by "sweating" the whole together with solder. After taping, if the work has been carefully done, there will be no difficulty in replacing the coils in the slot.

Repairs to the armature core are difficult to make without dismantling the machine; for while sometimes apparently satisfactory repairs can be made by driving the lamination into line and by filing, it is almost impossible to avoid short circuiting laminations which will allow eddy currents to flow and cause heating. Armature laminations are at times badly distorted by rubbing against the field poles due to a burned out bearing. It is then essential that the iron be put into good condition before any attempt is made to replace the repaired coils. If any considerable number of laminations have been burned together due to a ground, it is advisable to strip off the winding and to restack the iron, distributing the burned laminations throughout the armature.

Before assembling new laminations, they must be treated with a good core plate varnish. This may be done by hand or by dipping. A machine for performing this operation, described by J. M. Walsh in the Electrical World, consists of two printer's rolls placed one above the other, the lower dipping into a trough-like pan containing the varnish. The lower roll transfers varnish to the upper and the disks are fed between the rolls.

Drying Out

In case a generator has been exposed to rain or excessive dampness, it must be thoroughly dried out before being placed into service. With small machines and where an oven is available, this may be done by placing them in an oven with a temperature of from 100 to 150 deg. C. until the insulation resistance tests 500,000 ohms.

Large machines, however, are more conveniently dried out by sending low voltage current through the winding to heat them. This is done by opening up the shunt fields and short circuiting the armature by a conductor of low resistance and capable of carrying two to three times full load current. If it is a compound generator the series field should also be cut out entirely. The machine is now operated at normal speed and if the residual magnetism is strong enough a heavy current will circulate. If necessary, the shunt fields may be weakly excited from an external source until a current of from full load to twice full load flows. The temperature should be carefully watched and should not be allowed to exceed 80 deg. C. This may be controlled by adjustment of the field rheostat. Several hours and even days may be necessary in drying out large machines and during that time the temperature should never be allowed to fall below the temperature of the surrounding air, as moisture would probably condense

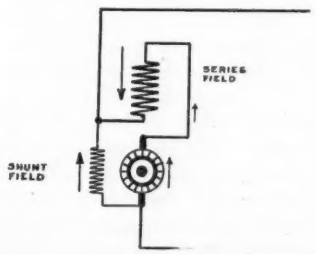


FIG. 11. DIAGRAM SHOWING REVERSED SERIES FIELD COIL

on the winding, thus bringing the machine back to the same conditions as at the start.

The field winding may be dried out by sending a low voltage current (about ¼ normal voltage) through them from an external source with the machine at rest.

Alternating current generators can be dried out by rotating the machine at any convenient speed and short-circuiting the armature with the ammeter in circuit. The field should be excited so that the desired heating current flows. The allowable temperatures range from 65 deg. to 80 deg. C., depending upon the voltage rating of the machine. The higher the rated voltage, the lower should be the drying out temperatures.

Opposed Fields

In connecting up the field coils of a generator, it sometimes happens that a mistake is made and one or

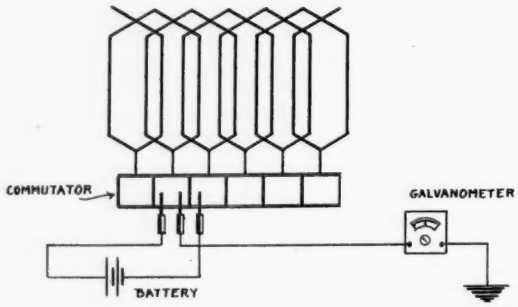


FIG. 12. METHOD OF TESTING ARMATURE FOR GROUND

more of the coils become reversed, i. e., they oppose each other. In a shunt machine, this will cause the machine to fail to generate full rated voltage or it may entirely fail to pick up.

With a compound machine, the series field coils may be reversed. If this happens, assuming that the shunt coils are connected properly, the machine will build up its load voltage without difficulty, but as soon as the load is applied, the voltage will decrease. This is due to the fact that as soon as the armature current begins to pass through the series field winding in the wrong direction, the series field will tend to oppose the shunt field, thus weakening it. This is true even in case the long shunt connection shown in Fig. 11 is used.

Reversed or opposed field coils may be tested by bringing a compass in close proximity to the field poles and noting the deflection. If two adjacent poles show similar polarity, the trouble is located and the connections should be reversed. This method of testing is not always advisable, for although simple and quick, it is subject to the disadvantage that the magnetism of the compass needle may become reversed. A more desirable test is as follows: bring the field up to normal strength and place two ordinary nails on adjacent pole tips, so that the point of one nail touches one pole tip, the other nail the other pole tip and the heads of the nails touch each other. Test all the poles in this manner noting whether the nails attract or repel each other. When the pole of reversed polarity is reached, the nails will repel each other.

Grounds and Shorts

For grounds in direct and alternating current generators and motors the most usual test consists in applying a high potential between the winding and the core; the potential depending upon the class of apparatus tested. In testing alternating current machines, a higher voltage is usually used than in direct current machines due to the former being designed to operate at higher voltages. When a ground develops in test, it can usually be located by the smoking of the insulation at the breakdown point.

A low resistance ground may be accurately located by the following method: A low voltage current sufficient to give a readable deflection on a galvanometer is passed through the armature from one commutator bar to one adjacent to it, as indicated in Fig. 12. One terminal of a galvanometer circuit the other side of which is grounded is then placed on one of the commutator bars. Each bar is tested in this manner until a full deflection is obtained, and a zero reading when the leads are moved one segment farther. The grounded coil then lies between these bars.

Armatures are tested for short circuits by the method indicated in Fig. 13. The voltmeter terminals are placed successively upon adjacent commutator bars. When the faulty coil is reached there will be little or no deflection.

A ground in an alternating-current armature may be located by the following method: First, measure the total resistance by means of a wheatstone bridge or otherwise, of the grounded phase; second, measure the resistance of the winding from one terminal to the other terminal. If the measurements have been accurately made, the sum of the last two measurements will be equal to the first. In Fig. 14, for instance, the resistance of the winding from A to B is 0.88 ohm, between A and G 0.23 ohm and between G and B 0.65 ohm. The location of the ground in this case is thus 23/88 of the distance between A and B measuring from A. If there

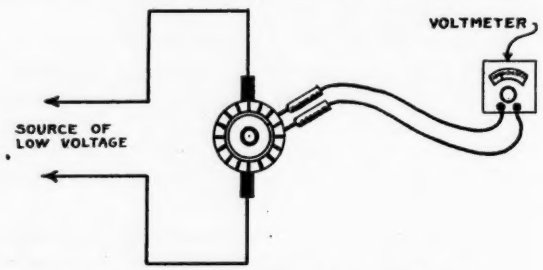


FIG. 13. TESTING ARMATURE FOR OPEN CIRCUIT

are twelve coils, it would indicate that the third coil was grounded.

Synchronizing

Synchronizing of alternators may be accomplished by the use of either lamps or instruments. The latter are termed synchronoscopes or synchroscopes depending upon the maker and consist of one or more magnetic elements so arranged and mounted that the difference in phase between two electromotive forces is indicated at every instant. If the incoming machine is running slow with respect to the machines already on the line, the pointer rotates continuously in the "Slow" direction as marked on the dial. If the incoming machine runs fast, the pointer rotates in the opposite direction. When the pointer stops, it indicates that the machines are running at the same frequency but they may not be in

phase; consequently we must wait until the pointer moves over the dummy pointer, thus indicating correct synchronism. The main generator switch is then quickly thrown in. It is almost impossible, however, to get the pointer to stop on synchronism, therefore the machines are adjusted so that the incoming machine runs slightly faster than that on the bus, with the pointer not revolving faster than one revolution in 6 sec. and then, as the pointer passes synchronism the switch is quickly closed. With automatic oil switches or remote control switches, the normal closing must be done slightly in advance of synchronism to allow for the "time lag."

When lamps are used, synchronism may take place either when the lamps are dark or when they are lighted depending upon the method of connecting. While the "dark" method seems to be preferred, it is open to the disadvantage that a broken filament would apparently indicate synchronism even though the machines were out of step. Closing of the switch at such a time would of course result in an accident. For this reason it is

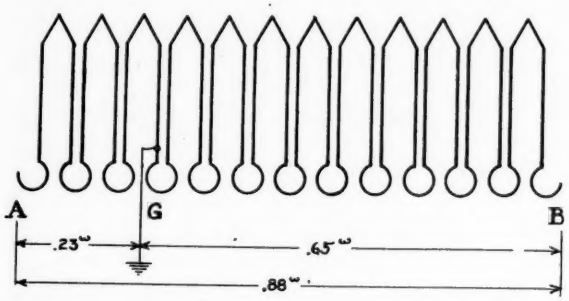


FIG. 14. DETERMINING LOCATION OF GROUND IN AN A. C. ARMATURE

considered desirable by some to reverse the synchronizing circuit connections, thus causing synchronism to be indicated at the "light" period. The time of greatest illumination, however, is difficult to determine and it is for this reason that the dark method is preferred. To guard against the possibility of a broken filament in the case of the "dark" method two lamps should always be placed in multiple.

Overhauling

It is desirable that a generator be given a systematic cleaning and overhauling at least once every year. Whether the machine apparently needs it or not, such a general overhauling will often reveal weak spots which might cause trouble later on.

The procedure employed in overhauling a machine will depend, of course, upon the size and type and upon the conditions under which the machine has been operating. The following instructions are only general and may be modified to suit conditions. They will serve, however, to give the reader an idea of what should be done and what to look for.

To begin with, open all switches connecting the machine to the line and make certain that all parts are dead. Remove the bearing caps and mark the position of the brush rocker arm so as to insure correct return to neutral when re-assembling. Before removing the armature, check its position between the field poles to see whether the clearance is uniform. Remove bearing pedestal at the end opposite to the commutator and block up the armature so that when the bearing is removed it will not fall upon the field poles. Now, with a chain block and by properly slinging the armature, withdraw the latter from its position in the generator and place it between suitable supports so that it can be rotated and thoroughly inspected. Blow out all windings with compressed air and clean with gasoline.

Examine the commutator for loose bars or connections. If the shaft is roughened or cut, true it up before any bearing sleeves are repaired. Have bearings scraped or rebabbited if necessary.

See that all field poles are securely fastened to the frame yoke and, if any are found loose, tighten them. Armature as well as field coils and all leads may be painted with insulating varnish, if desired. Do not paint pole shoes nor the armature core disks as this might result in insufficient clearance between these two parts and cause the armature to freeze between the poles if shut down for any length of time. Before painting, examine armature and field windings for places where the insulation has cracked or peeled off and use tape and shellac to repair such faulty spots.

Examine armature band wires for tightness and slip mica under them, if loose.

Clean the brushes one set at a time to avoid mixing them up and replace worn ones with new ones. Renew weak springs and give all brushes the same tension. See that all pigtails are tight.

In re-assembling be sure to get the armature exactly in the center of the field poles by adjusting the bearings. If bearings have been rebabbited, see that they are grooved for oiling and that all grit has been removed before replacing the bearing caps.

Motors

Important Considerations in the Control, Operation and Repair of Direct and Alternating Current Motors

It is an inherent characteristic of an electric motor, regardless of type or size, to draw an unduly large current during the interval of starting. This is due to the fact that when the motor is at rest there is an entire absence of counter-electromotive force, consequently, at first moment of starting the current flowing through the armature is limited only by the resistance, or impedance in the case of an alternating current machine, of the winding. This being comparatively low in most cases, the current is large.

To limit this abnormal initial rush of current to a reasonable value, it is essential in all cases where the motor is of a size, say over 1 hp., to provide some arrangement for starting the motor. With direct current motors this is usually accomplished by introducing a resistance into the armature circuit during the starting interval, this resistance being cut out gradually as the motor speeds up. In alternating current work, the impressed voltage is generally reduced to a low value at starting by connecting an auto-transformer or compensator into the circuit until the motor has attained nearly full speed, after which the starting switch is thrown to the running position which connects the motor directly to the line.

Of starting boxes and speed control apparatus, there is an almost infinite variety. Although the constructional features of these may differ considerably, the main operating principles are practically the same. There is generally a starting resistance which is gradually cut out as the speed of the motor increases; provision for connecting the shunt field directly to the line in the case of shunt or compound wound motors; a no-voltage release which brings the control lever or levers back to the "off" position if the voltage fails; an overload release which acts as a circuit breaker on heavy overloads.

For controlling the starting current to alternating current motors, particularly induction motors, a starting switch is usually provided. This switch, which may or may not be integral with the compensator case, as a rule has only two positions, i. e., "start" and "running." A simple diagram of connections of the starting compensator for a three-phase induction motor is shown in Fig. 1. When thrown to the starting side, the autotransformer is in circuit. This device is equivalent to a single coil step-down transformer, the ratio of transformation being that existing between the total number of turns across which the primary terminals are connected and those between which the load is placed.

In operating starting boxes, too much time must not be taken in getting a motor under way. It is exceedingly rare that 15 or 10 sec. is not sufficient. If more time than that is taken, the resistance will begin to overheat unless an extra large sized rheostat is used. In order to reduce the first rush of current when the circuit is closed, it is sometimes advisable to insert an extra amount of resistance in the starting rheostat. Should the motor be heavily loaded, it will consequently not

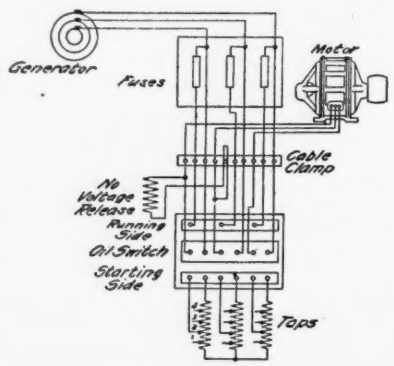


FIG. 1. CONNECTIONS OF THREE-PHASE STARTING COMPENSATOR WITH LOW VOLTAGE RELEASE AND FUSES

start when the rheostat lever is on the first segment and it frequently becomes necessary to move the lever to the second and even to the third segment before the motor will start. If the motor does not start when the rheostat lever is on the first segment, the lever should be promptly moved to the second or third segment, thus avoiding overheating the resistance.

A double-pole knife switch should always be placed between the starting box and the line. The circuit to the motor must be opened by pulling this switch, never by pulling the lever on the starting box back to the "off" position, as this is liable to draw a large arc. If the motor does not start on the first, second or third segments, do not interrupt the circuit by pulling back the lever, but use the knife switch instead.

Multiple starting rheostats for a.c. slip ring motors in which a number of separate switches are used to cut out resistances in starting, instead of by the sliding-contact method described above, should be operated rapidly. Until the last switch is closed and held by the release magnet, the other switches will not remain closed. The first switch is held closed by the second, the second by the third and all by the last switch.

All rheostat contacts will arc and burn unless they are kept clean. Dirt is not a good conductor of electricity. When a contact once begins arcing, this action

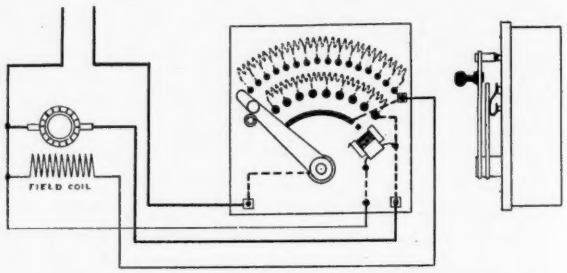


FIG. 2. COMBINED STARTING AND FIELD CONTROL RHEOSTAT

will rapidly increase unless the contact is immediately cleaned. If it is burned badly it should be replaced by a new one.

Stopping Motors

In stopping an unloaded shunt or compound motor, it is merely necessary to pull the main switch between the line and the starting box. The torque required to maintain the speed of a motor running idle is low, being only that necessary to overcome the no load losses. The armature current, therefore, is also low and will not cause any noticeable disturbance of the line voltage if it is suddenly cut off.

The torque and the armature current of a motor operating under load on the other hand may be very high, depending, of course, upon the size of the motor and load. It is, therefore, obvious that if such a motor were suddenly taken off the line, it would in all probability cause a violent fluctuation in the line voltage which would affect remote parts of the circuit. In order to prevent such a disturbance, it is desirable whenever a large motor, heavily loaded, is to be stopped, first to reduce the speed and armature current by cutting resistance (not the starting resistance) into the armature circuit. When the current reaches a sufficiently low value, the main switch may be pulled, thus disconnecting the motor from the line.

The same result may be obtained by first removing the load from the motor (if this is possible) and then following the procedure described for stopping unloaded motors.

Controllers

There are two principal methods of controlling the speed of direct current motors, namely, armature control and field control. While there are also a number of other methods, the two referred to are the only ones in general use. The armature method of control consists in varying the resistance of the armature circuit

by means of a rheostat. It is extensively employed in controlling the speed of series motors, but is open to the objection that a considerable amount of energy is lost in the form of heat in the rheostat. Hence, wherever conditions permit, in the case of series motors, the series parallel control is used. This is used in practically all street railway work and consists in varying the speed of the various motors by connecting them in series or parallel in combination with suitable rheostats.

The field method of speed control is used in connection with both shunt and compound motors. It consists essentially in varying the shunt field current by means of a rheostat. As the speed of the motor, particularly the shunt type, varies inversely as the field strength, it is evident that an increase of resistance of the field circuit will result in an increase of speed.

The field control rheostat may be entirely separate from the starting rheostat or it may be incorporated with the latter as shown in the diagram, Fig. 2.

The speed control of alternating current motors is as a rule more difficult and the results obtained are

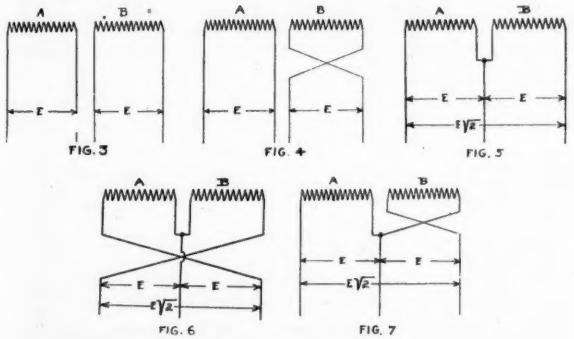


FIG. 3. TWO-PHASE 4-WIRE MOTOR DIAGRAM

FIG. 4. REVERSING ROTATION OF MOTOR SHOWN IN FIG. 3 BY REVERSING LEADS TO ONE PHASE

FIG. 5. TWO-PHASE, 3-WIRE MOTOR CIRCUIT

FIG. 6. TWO-PHASE, 3-WIRE MOTOR CIRCUIT WITH OUTSIDE LEADS REVERSED

FIG. 7. CHANGING DIRECTION OF ROTATION OF MOTOR SHOWN IN FIG. 5 BY REVERSING TERMINALS OF ONE PHASE

less satisfactory than in the case of direct current motors. The speed of synchronous motors, of course, is dependent only upon the frequency of the circuit and is only applicable in places where a constant speed machine is desired. The induction motor, although substantially a constant speed machine, its change in speed between rated load and no load being usually from 4 to 8 per cent, is capable of having its speed controlled by a number of methods, enumerated as follows:

Adjustment of primary voltage.

Variation of the number of poles.

Variation of the frequency of primary current.

Adjusting the resistance of the secondary (rotor) circuit.

Cascade connection, i. e., operating two or more motors connected in cascade, or series.

While the second method listed is coming in favor in certain applications of the induction motor, as for instance, in connection with electrically driven ships, the speed changes available are more or less limited. In the variation of potential method the connections are substantially the same as those of the compensator starting device, Fig. 1, described under "motor starting," except that the contactors slide over the taps instead of being fixed in position. This method is not in general use, however, and the speed regulation obtained by it is very poor, while the efficiency and power factor decrease rapidly with the speed.

Speed control by varying the resistance of the rotor circuit is more satisfactory than the method just described, and although the speed is not constant over the torque range, it is useful where constant speeds are not essential, such as in the operation of elevators, hoists, etc. It is necessary, of course, that an induction motor controlled by this method be provided with a wound rotor. The Y connection is generally employed and an adjustable resistance is placed in series with each phase.

Lubrication

THE LUBRICATING requirements of motors do not differ materially from those of generators and what was said under generator lubrication applies equally well to motors. Motors located in more or less remote and inaccessible places are apt to receive less attention than generators; the bearings of electric motors should, therefore, always possess a certain reservoir capacity in order that they will not run dry. Where motors are installed in dusty places, the bearings should be provided with dust proof coverings.

Reversing Rotation

THE DIRECTION of rotation of a direct current motor may be reversed by reversing the direction of the current through either the armature circuit or the field circuit but not through both. Merely interchanging the line connections to a motor will not change the direction of rotation. When it becomes necessary to reverse the direction of rotation of a compound wound motor, it must be remembered that the direction of current through both the series and shunt fields must be changed. Reversal of only one of the fields would cause the fields to oppose each other.

It is desirable in most cases when a reversal or rotation is required that the current through the armature be reversed rather than that through the fields. This is because of the fact that on starting the magnetism of the reversed winding might oppose the residual magnetism of the field poles and thus prevent the machine from building up.

Polyphase alternating current motors may have their direction of rotation reversed by interchanging the leads to one of the phases. For instance, in the case of a two-phase, four-wire motor, such as depicted diagrammatically in Fig. 3, the rotation may be reversed by interchanging the connections as shown in Fig. 4. A two-phase, three-wire motor, Fig. 5, will have its rotation reversed by changing the connections to the outside leads as shown in Fig. 6 or by reversing the terminals of one of the phases as shown in Fig. 7.

For a three-phase connection, the rotation will be reversed by interchanging the connections of any two leads to the motor.

Loose Connections

In induction motors with squirrel-cage armatures, trouble may be encountered due to loose or imperfect connections between the armature bars and the end rings. This may be due to poor soldering or the use of an improper flux in soldering which in time develops poor electrical contacts due to chemical action at the joints. If only a few of the joints on the rotor are thus affected there will be a lowering of the speed and unbalanced currents will flow. If all the joints are affected there will be local heating at the joints together with a lowering of the speed.

Reversed Phases

Reversed phases is a term applied to a particular type of fault sometimes encountered in induction motors which have been newly received from the manufacturers or which have been newly rewound. The fault exists only in three-phase motors, and is the result of reversing one of the phase windings so that the voltages in the three windings are displaced only 60 deg. from each other. In an ordinary three-phase alternating current circuit the voltages are usually 120 deg. apart as shown in Fig. 8a. From this diagram it will be readily seen that the effect of reversing one of the phases will cause the voltages to be displaced 60 deg. as shown in Fig. 8b.

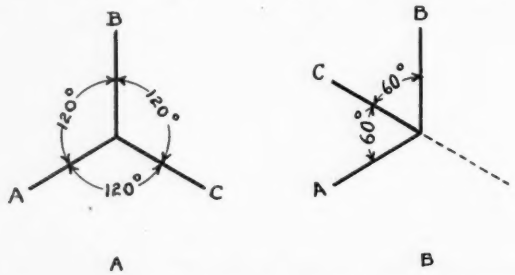


FIG. 8. DIAGRAM SHOWING THE EFFECT OF REVERSING ONE OF THE PHASES UPON THE VOLTAGE RELATIONS

Under such conditions the motor will not operate properly and the fault may usually be recognized by the following symptoms: refusal of rotor to move or if it does, rotates at a very low speed; marked unbalanced currents flowing; machine emits a loud growling noise; and excessive local heating.

The fault may also be determined before the motor is connected to the line by the following method of test. Remove the rotor from the machine and excite the stator windings from a source of direct current, of a voltage, say from one-fourth to one-third the normal value of the alternating voltage. If the winding is Y connected, excite only one phase at a time by sending the direct current from each lead to the star point. Now by passing a pocket compass slowly around the bore of the motor, test out the polarity and mark the poles plus or minus with chalk on the respective pole pieces. Make three separate tests in this manner, one on each phase winding; if the observations have been correct, at the end of the test there will be chalk marks on all poles and the marks will indicate north and south alternately. Reversal of one phase is indicated when like poles are adjacent.

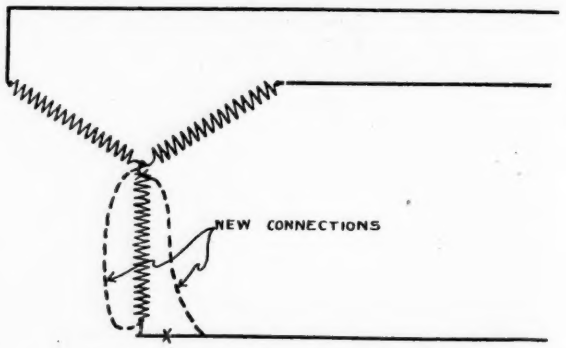


FIG. 9. SHOWING METHOD OF REMEDYING TROUBLE DUE TO REVERSED PHASES IN A STAR CONNECTED MACHINE

In the case of a delta connected machine, the stator winding is opened at one lead and the three windings excited in series.

To remedy this fault in a star winding, interchange the connections of the reversed winding by opening up the star point and by connecting the end that was the lead end to the star point, as shown in Fig. 9.

Electric Circuits

Methods of Installation, Operation and Repair

GROUNDS ARE accidental electrical connections between one side of an electrical system and the ground or any conductor connected to the ground. Electric circuits of all types whether installed above ground or underground are subject to this type of fault, and while a single ground is not always detrimental to the satisfactory operation of the circuit, in many instances it will result in complete shutdown of the branch of the system on which it occurs.

Grounds are due to a number of different causes, and no attempt will be made to enumerate, here, all the possible conditions which may contribute to their cause. The more important causes, however, are as follows:

Carelessness or poor workmanship in installing conductors; deterioration of insulation due to heat, moisture, chemical fumes, etc.; vibration causing the insulation to be worn through by constant rubbing; excessive potentials causing the insulation to break down; excessive currents, causing heating of conductors with consequent burning of the insulation; moisture, causing insulation failure.

A single ground, as stated previously, will cause no trouble, in fact, two or more grounds may exist on the same side of the line without causing any harmful effects. It is when two grounds occur, one on each side of the circuit, that trouble develops.

To prevent the existence of even one ground, it is customary to install ground detectors on the circuit which not only indicate the occurrence of a ground, but also the particular line on which it occurs. The location of the fault must then be determined and removed before another ground occurs.

Determining the location of a ground is largely a matter of elimination, a systematic division of the system into convenient parts or sections being the first requisite. A thorough inspection of each branch should be made before any attempt is made to remove wires from conduit, and in testing, it is customary to begin with the branch nearest the source and continue outward.

A lamp testing set is commonly employed in this work. Beginning at the fuse box nearest the source apply the terminals of an incandescent-lamp testing set between the conduit or other ground connections and the line, testing each side of the line separately. If the lamp lights up, the ground exists on some point beyond, on the wire which does not cause the lamp to light. At the first junction box on the main line determine as before, which wire is grounded. Take out the fuse in that wire and note whether the ground disappears. If it does, the ground is on the wire which was unfused. If the ground is not on that circuit proceed to the next and repeat the test until the grounded section is disclosed. When the grounded branch is found, open up the line successively at the various junction boxes and test in the same manner as described above until the particular section of conduit on which the ground exists is reached. The wires should then be pulled from this section for examination and repair.

TABLE I. TYPES OF INSULATION FOR USE IN VARIOUS LOCATIONS

Kind of Location	Open Wiring	Conduit Wiring
Cool and dry	Slow burning	D.B. rubber
Cool and wet	Rubber S.B.	S.B. rubber
Hot and dry	Slow burning	Slow burning (special consent required)
Hot and wet	Rubber	Satisfactory installation difficult
Fumes present	Slow burning weatherproof	Satisfactory installation difficult

Voltages are 550 or below.

S. B. = Single braid. D.B. = Double braid.

Breaks

A BREAK or open circuit in an electrical system is generally disclosed by the point on the circuit beyond

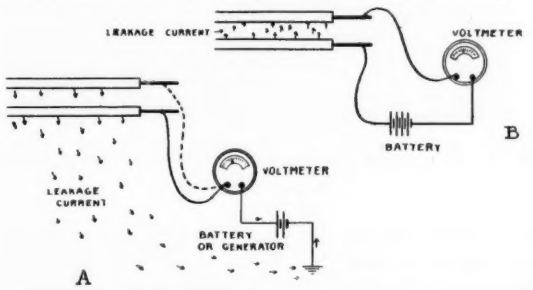


FIG. 1. SIMPLE METHODS FOR MEASURING THE INSULATION RESISTANCE

which lamps, motors or other electrical apparatus connected to the line refuse to operate.

In case, however, it is desired to test a newly installed circuit for opens and where the power or lighting current is not available, the following method of test may be employed. Ground the two or more conductors of the circuit at the point nearest the source. Then by means of a testing set made up of an electric bell in series with a dry cell, test each portion of the system successively at each outlet or junction box by applying the terminals of the test set between the ground and one of the conductors. Test each conductor separately. If the bell rings it indicates that the circuit is intact, if not, that an open exists in the particular section under test.

Repair of a break may be effected by pulling the portions of the faulty conductor from the conduit and splicing it or replacing it with a new one. In making a splice, care must be taken to tape the joint in such a way as to make the thickness of the insulated joint equal to the thickness of the wire itself, otherwise the difficulty will be experienced in pulling the wire through the conduit.

Insulation

THE INSULATION requirements of any electrical system depend upon the voltage at which it is operated, the higher the voltage, the more effective must be the method of insulation. All conductors must be insulated for their entire length with a properly applied and properly vulcanized rubber compound. In the installation of inside wiring it is important that the Underwriters' Rules and

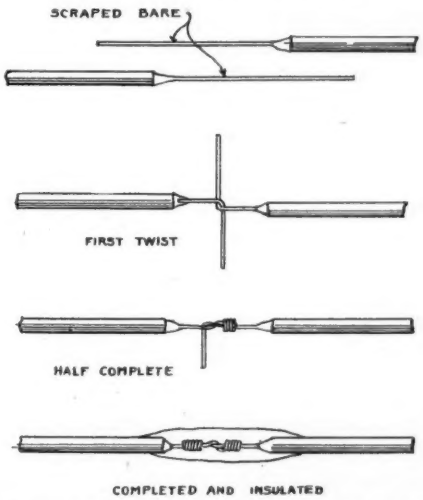


FIG. 2. SHOWING STEPS IN MAKING A WESTERN UNION JOINT

all local ordinances be observed. Table I gives the kinds of insulation suggested for use in various locations based on the 1920 Electrical Code and on the Factory Mutual Fire Insurance Company's Wiring Rules.

The insulation resistance of a circuit may be determined by means of a voltmeter of known resistance (preferably a high resistance) in series with a source of electromotive force. When the apparatus is arranged as shown at A in Fig. 1, the resistance from each side of the circuit to the ground is measured. When connected as shown at B, the insulation resistance between the two wires is measured. The insulation resistance R of the line can then be calculated by the following formula:

$$R = r\,\frac{E - E'}{E'}$$

in which r = the resistance in ohms of the voltmeter
E = the voltage of the battery or generator
E′ = the voltmeter reading when placed in series with the insulation.

In testing the insulation resistance between the two lines it is understood of course, that all current consum-

ing devices must be turned off or disconnected while the test is being made.

The National Electric Code requires that each branch circuit, in the wiring of buildings, have an insulation resistance of at least 100,000 ohms.

Professor Jamison's rule for the required value of insulation resistance is stated as follows: The resistance to ground should be equal to

$$100{,}000 \times \frac{\text{E. M. F.}}{\text{number of lamps}}$$

If the insulation resistance when measured is found to be too low, it may be that a ground or several grounds have occurred. These should, of course, be removed immediately. If no ground can be located, however, the entire system must be carefully examined and more effective insulation installed wherever it is deemed necessary.

Joints

Joints and splices in electrical conductors, according to the rules of the National Board of Fire Underwriters must be mechanically and electrically secure without the use of solder. They must then be soldered unless made with some form of approved splicing device and covered with an insulation equal to that on the conductors. These requirements apply both to inside and outside wiring.

FIG. 3. SPLICING LARGE WIRES BY WINDING FINE COPPER WIRE AROUND JOINT

Perhaps the most common type of joint and one which is simply made is the "Western Union" joint illustrated in Fig. 2. It is extensively used both on inside and outside wiring. The method of making this joint is well illustrated in the sketch and needs no detailed explanation.

In making any joint, care must be taken to remove all insulation from the ends to be joined and to scrape them clean and bright with a knife or with sandpaper. Joints in wires of comparatively large diameter, say larger than No. 8 B. & S. gage, are made by scraping the ends for a distance of about 4 in., placing them adjacent, and then winding fine copper wire around the joint as illustrated in Fig. 3. The entire splice is then soldered and taped.

There are a number of sleeves and patented joints upon the market which, when properly applied, aid in making a splice effective, both mechanically and electrically. These are especially applicable in splicing heavy cables or line wires, as illustrated in Fig. 4.

If the ends of two conductors are badly joined, the electrical resistance is increased and the passage of current through the joined conductors will develop heat at the joint. Joints may be soldered either with a blow torch or a soldering iron. The use of acid soldering flux should be avoided in soldering electrical conductors as it may cause high resistance joints due to corrosion. A good solution for use in soldering copper wires may be made up as follows: Saturated solution of zinc chloride, 5 parts; alcohol, 4 parts; glycerine, 1 part.

The effectiveness of any joint can be accurately determined with a millivoltmeter and an ammeter, by sending a current through the joint and noting the voltage drop across it. The resistance of the joint can then be calculated from Ohm's law. In ordinary commercial work, however, this exact method of determining the resistance is not necessary. It is sufficient to test the effectiveness of the joint by bridging it with a lamp in series with a battery or other source of current and noting whether the lamp lights up or not.

Resistance

In measuring the resistance of any electric circuit, the selection of the method of test will depend upon the degree of accuracy required and upon the kind of circuit to be tested, i. e., whether of low, medium or high resistance.

FIG. 4. SPECIAL TYPE OF JOINT USED FOR HEAVY CABLES

Probably the simplest method of determining the resistance of a circuit is by what is known as the substitution method. In employing this method, the circuit to be tested is placed in series with a battery of constant electromotive force and a galvanometer, and the deflection of the latter carefully noted. The circuit or unknown resistance is then replaced by an adjustable resistance, the adjustment of which is varied until the same deflection is again obtained. The value of the adjustable resistance is then equal to that of the resistance to be measured.

The resistance of medium and high resistance circuits is most suitably determined by means of any of the Wheatstone bridge methods. A simple application of this method is shown in Fig. 5. A, B, and R, are known resistances, the first two, in practice, being made even multiples of ten. The resistance R, is adjusted until there is no deflection of the galvanometer when both keys are closed. When this condition prevails, the bridge is said to be balanced, and the resistance of the circuit, x, may be calculated from the formula

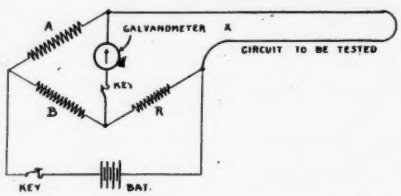


FIG. 5. MEASUREMENT OF RESISTANCE BY THE WHEATSTONE BRIDGE METHOD

$$x = R \times \frac{B}{A}$$

In taking circuits of very low resistance such as bus bars or heavy feeder cables, the millivoltmeter method described under the subject of "Joints" may be employed.

Interior System

It is necessary that the design and installation of all interior wiring shall conform to the local requirements of the state or city in which the system is situated. These local requirements sometimes differ from the recommendations of the National Fire Protection Association, and being laws, they take precedence over the latter. In the absence of local regulations, the recommendations of the National Fire Protection Association should be followed in all cases.

With the exception of the wire used in fixture work, no conductor must be of a smaller size than No. 14 B. & S. gage, and must be insulated with an approved rubber covering. All conductors, whether insulated or not, should be treated as though they were uninsulated,

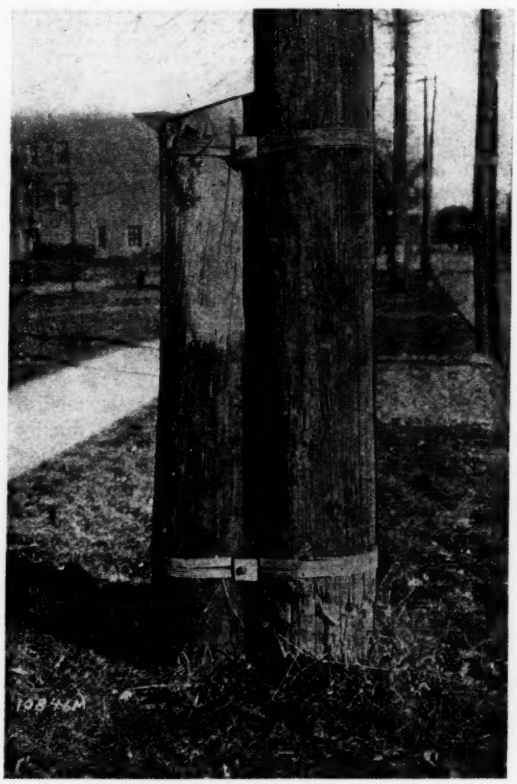


FIG. 6. METHOD OF REINFORCING DECAYED POLE BY MEANS OF A BRUSH TREATED STUB

so that the danger of leakage to ground or of short circuit may be reduced to a minimum.

In calculating wire sizes for two-wire direct current circuits of ordinary length, it is first necessary to determine the load in amperes that the circuit will carry, then to find the distance from the center point of distribution to the load center of the circuit, and then to decide the allowable voltage drop.

The load center usually can be estimated by inspection but can be calculated accurately by multiplying the normal current taken by each current consuming device by its distance to the central distribution point, adding these results, and then dividing by the total current in the circuit. The wire size, for copper wire currents may be calculated by the formula

$$A = \frac{10.75 \times l \times I}{e}$$

in which A is the area of the wire in circular mils; l is the length of the circuit measured one way; I is the current in amperes and e is the allowable voltage drop. In the case of balanced three-phase, three-wire a.c. circuits, the area of the conductor is given by the formula

$$A = \frac{10.75 \times l \times I \times 1.73}{e}$$

In the installation of interior systems of wiring, two principles must be kept in mind: 1. The wires must be so installed as to eliminate fire hazard. 2. Wires must be protected from injury. To conform to these requirements, it is essential that the wire be selected and installed to meet the conditions under which it operates; often several different methods are necessary in the same plant. Conduit wiring is not always satisfactory. Some chemical plants, for example, are so filled with corrosive vapors that both pipe and wire covering are destroyed. In such places fiber duct may be used to advantage. In installing this, care must be taken effectively to seal

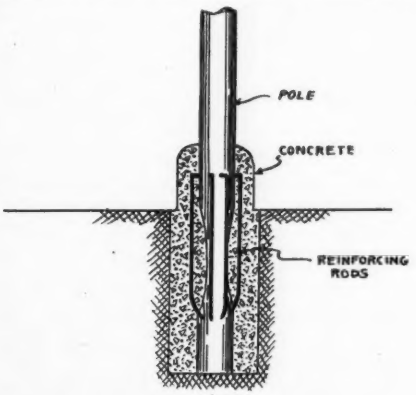


FIG. 7. METHOD OF REINFORCING POLE WITH CONCRETE

the ends so that the corrosive vapors cannot enter and destroy the insulation on the wire. Such ducts must be supported by planks or beams coated with tar or other acid resisting compound.

Pole Lines

Poles for supporting the conductors of transmission lines or outdoor distribution systems should receive periodic inspection for the purpose of ascertaining whether or not they are rotting at the ground line, for that is the point where failure usually occurs. This, of course, refers particularly to wooden poles.

New poles should be selected according to some standard set of specifications such as may be found in the reports of the overhead system committee of the National Electric Light Association. These specifications are the culmination of years of experience and observation of various member companies and are probably the most complete specifications for pole line construction that have ever been compiled.

In case poles are found to be in an unsafe condition due to rotting at the ground line, they may be repaired by several different methods. If the pole is in bad condition at its base, it can be chopped off just above the

ground line supporting it in the meantime with 3 or 4 pole pikes. By then setting the lower portion of the pole to one side, the old butt can be dug out of the ground. The shortened pole is then lowered into the hole. If desired, before lowering it into the hole the base of the pole may be brush treated with creosote or carbolineum as an aid to preservation.

The method of prolonging the life of old poles just described is open to the objection that the pole is shortened. In cases where this method is not feasible, the old pole may be reinforced by means of a brush treated stub as shown in Fig. 6. A still better method of repair is by reinforcing with concrete as shown in Fig. 7. Mild steel rods ½ in. in diameter, about 5 ft. long, pointed at both ends, with the upper end bent at right angles are used for reinforcing.

The type of insulation to be used on any particular pole line will depend to a large extent upon the voltage

TABLE II. PERMISSIBLE SAG IN ANNEALED COPPER LINE WIRES

Span in Feet	Sag in inches						
	Temperature in deg. F						
	30	40	50	60	70	80	90
50	8	9	9	10	11	11	12
60	10	11	11	12	13	14	14
70	11	12	13	14	15	16	17
80	13	14	15	16	17	18	19
90	14	16	17	18	19	20	21
100	16	17	19	20	21	23	24
110	18	19	21	22	24	25	26
120	19	21	23	24	26	27	28
140	22	24	26	28	30	32	33
160	26	28	30	32	34	36	38
180	29	32	34	36	39	41	40

of the circuit. The higher the voltage, the greater will be the cost of the insulation. For comparatively low voltages, glass insulators are to be preferred. Glass, although an excellent insulator, is subject to surface leakage due to the condensation of moisture on its surface. Porcelain is superior to glass in this respect and for that reason, although higher in price, is used on the higher voltage circuits. It can also withstand considerable temperature changes without danger of failure.

In dry localities where long rainless summers prevail, insulators at times become coated with dust and salt. The effect of frequent cleansing rains in transmission line operation is therefore beneficial. In dry regions such as just referred to; it is therefore advisable when the insulators become coated with salt or dust, to wash them. This also applies to regions such as the Pittsburgh district where a combination of soot and fog causes trouble.

Line wires on outdoor pole lines must be so placed that moisture cannot form a cross connection between them and must be not less than one foot apart except when in the form of multiple conductor cable. The spacing of the wires of course is determined by the spacing of the pins on the cross arms. These should be spaced to provide safe working room for the linemen and should take into account the average sag of the wires. Center pins should not be spaced less than 30 in.

The sag in the line wires is dependent upon the pole spacing, the temperature, and the tensile strength of the wire. Ordinary soft drawn copper wire has an ultimate tensile strength of 34,000 lb. per sq. in. but the working strength should not be over one-fourth of this. The proper sag for conductors of soft drawn copper for various spans and temperatures may be obtained from

TABLE III. DEPTH OF HOLES FOR POLES

Length of Pole	Depth.	
	Straight Lines	Curves
Up to 30 ft.	5 1/2 ft.	6 1/2 ft.
30-40 ft.	6 ft.	6 1/2 ft.
45 ft.	6 1/2 ft.	7 1/2 ft.
50 ft.	7 ft.	

This table is based on good soil conditions. If soil is poor, poles must be set deeper, reinforced with concrete, or set in barrels filled with stone or gravel.

Table II which was taken from the reports of the National Electric Light Association.

There are two ordinary methods of setting poles, namely, the "pike pole" method and the "gin pole" method. The latter, however, would hardly be justified unless a large number of poles were to be set. The pike pole method is described as follows:

The post hole having been dug to the depth indicated in Table III, and of a diameter sufficient to permit the use of tamping bars when filling, a plank 10 or 12 in. wide is placed in it and allowed to project above the ground about 2 ft. This plank provides a smooth surface for the butt of the pole to slide over during the process of erection. The pole with the cross arms bolted to it and the insulators screwed in place, is laid with its end butting against this plank. It is then raised as high as possible and rested on some support until the pikes can be gotten into place, after which the lifting

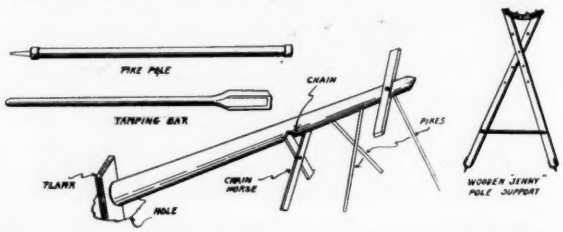


FIG. 8. METHOD OF RAISING POLE AND TOOLS EMPLOYED

process is continued until the pole drops in place. Figure 8 shows, roughly, this method and some of the tools used.

After the poles have been set and "plumbed," that is, set vertically, the wire should be strung. This is done by taking the end of the wire from the coil and passing it over the cross arms, pulling it tight enough to provide the proper sag, and then tying it to the insulators by means of "tie wires."

In all cases where spare circuits are available, or where load conditions are such that the line can be taken out of service for repairs during normal working hours, live line maintenance is not to be recommended. On systems loaded so heavily that lines cannot be released for repairs, the use of live line maintenance may be

considered if proper safeguards are provided. The nature of these safeguards will depend largely upon the voltage of the system. An important point to be considered in this matter is that of proper clearances, although even here a number of variables have to be considered. For instance, clearances that would be entirely satisfactory on a pole line carrying one circuit would not be sufficient for a line of two or more circuits. The use of wood or metal cross arms and the presence of grounded construction on the poles are also factors affecting the situation. On comparatively low voltage work where more than two circuits are frequently carried on a single-pole line, it is particularly important to maintain adequate climbing space so that the men will have room not only to climb through the construction but also to use their tools with safety.

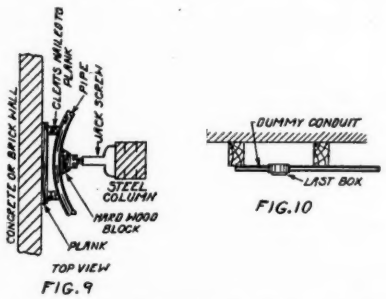


FIG. 9. USING A JACKSCREW AS A PIPE BENDER
FIG. 10. METHOD OF "OVER RUNNING" CONDUIT TO PROVIDE SUPPORT

In the maintaining of live transmission lines, some companies provide an insulated staging to be attached to the towers or poles on which the men stand while working on the lines. Where necessary, wood barriers are placed around any grounded parts of the poles so that the men cannot come in accidental contact with them.

Conduit Systems

Rigid iron conduit wiring is probably the best form of wiring and should be installed wherever the importance of the installation warrants the expense. In many localities, the ordinances require that all concealed work shall be of this type. In some cases, however, it will be found easier to use flexible metallic conduit and where the ordinances permit, it may be used in place of rigid conduit.

Black enameled conduit is used almost exclusively for interior work. For outside installations, it is customary to use galvanized or sherardized iron conduit in order to lessen the danger of rusting.

One of the advantages of conduit wiring over other forms of wiring is that it effectively protects the conductors and at the same time provides a smooth raceway through which conductors may be readily drawn in or removed. If, however, in the installation of a system, a size of conduit is selected too small comfortably to accommodate the wires, they will become wedged in, particularly in warm locations and removal will be impossible.

To preclude such a condition, it is important when installing or laying out a conduit system to select conduit of a size large enough so that no great amount of force will be required to pull the wires through. It should never be necessary to resort to the use of a block and tackle when pulling in small or medium sized conductors.

When three-wire systems are to be installed with a neutral wire twice the size of the outer wires, a conduit should be selected large enough to accommodate four wires the size of the outside conductors.

Except in the case of signal wiring, the installation of conduit smaller than ½ in. electrical trade size is not permitted. The conduit must be continuous from outlet to outlet or to junction boxes or cabinets and must enter properly and be secured to all fittings. The entire system must be mechanically secured in position and installed as a complete system without the presence of the conductors. It is also required that the conduit system be grounded permanently and effectively.

The wires used in conduit work must have an approved rubber insulating covering and within the pipe must be without splices or taps. Duplex wire, particularly No. 14, is largely used for branch circuits. Solid wire is used for conductors up to, and including No. 6, but conductors larger than this should be stranded so that they may be readily pulled into the ducts.

In alternating current work it is essential that the two or more wires of one circuit be installed in the same conduit to prevent inductive voltage drop and dangerous overheating of the conduit due to induced currents. Even when installing conductors for direct current circuits it is a good plan to include the two conductors in the same duct, so that if at any time it should become necessary to convert the system from the use of direct to alternating current, it may be done without extensive alterations.

The same conduit must never contain circuits of different systems.

In installing a conduit system, the following are the various steps in the order usually gone through, cutting,

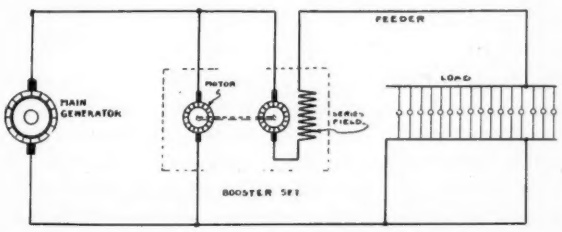


FIG. 11. SHOWING THE USE OF A BOOSTER TO COMPENSATE FOR LINE DROP

reaming, threading, bending, hanging, connecting, fishing, pulling, and splicing. The first three operations can be done either by hand or by machine. When done by hand the cutting should be done with a hacksaw rather than with a pipe cutter.

Reaming can be done with a half round file or with a reamer. The edge should be carefully taken off so that when the pipe butts together inside of the coupling it will not be upset into a cutting edge.

When threading, to avoid frequent changes in the "set up," all conduit of one size should be cut at one time.

The methods to be used in bending conduit depend on the size of the pipe. Pipe of large size requires the

use of jackscrews or other mechanical appliances, while the smaller sizes can be bent with a hickey or in the case of ½ in. pipe, over the knee. On pipe 2½ in. and up, the use of a jackscrew becomes necessary. Figure 9 shows one way in which this can be done. The cleats and the hardwood block should be grooved to fit the pipe approximately. The conduit should be moved along so that the curve will be symmetrical.

In mill-type buildings it is common practice to have all of the conduit suspended from the floor beams and roof trusses. While there are on the market a number of pipe hangers designed for attaching conduit to the flanges of I-beams, many are so flimsy as to be worthless for any except the smaller pipes, say ½, ¾, and 1 in. For the larger ones, there seems to be nothing better than the clumsy old-fashioned pipe clamps. On wooden beams, the fastening of conduit is simple, as an ordinary strap will fill every requirement.

All fittings must be firmly fastened in place. In case an outlet box happens to come halfway between two beams or trusses, it is advisable to install a dead piece of pipe to the next beam to serve as a support as shown in Fig. 10.

In installing a number of parallel runs of conduit, it is advisable to run them simultaneously. This usually makes it possible to produce a more symmetrical job than if each line were run alone and permits of the economical use of portable platforms on which to work.

Where it is necessary to make 90-deg. turns in single runs of large conduit it is usually more economical to use factory ells than to bend the pipe. If two or more pipes run in parallel, a neater job can be made by bending them as by so doing they can be kept parallel in the curves.

The number of pull boxes to be installed in a given run cannot be given in any definite way. It is as a rule not practical to pull conductors past more than the equivalent of four pull boxes. Heavy cable cannot be pulled past more than two 90-deg. elbows, and it is better to install too many than too few pull boxes when dealing with heavy cables.

Boosters

In cases where direct current of comparatively low voltage must be transmitted over long distances it is not always economical to install conductors of a size large enough to prevent an undue drop in voltage. Neither is it feasible to raise the voltage of the generator sufficiently to deliver the required voltage on account of the excessive voltage fluctuations which would result from changes of load.

To compensate for the drop in such cases, a "booster" is connected in series with the feeder, as shown in Fig. 11. Such an arrangement automatically maintains the voltage at the required point, as long as the generator delivers normal pressure.

A "booster" is nothing more than a series generator driven by a shunt motor. As indicated in the diagram, the generator is connected in series with the feeder so that the generator field will be excited in proportion to the current flowing in the feeder. The armature of the generator being independently driven at constant speed, it is evident that any increase in feeder current will increase the voltage of the generator. This electromotive force is added to that of the main generator or will oppose it depending upon the manner in which the terminal connections are made. In this manner the voltage is automatically varied to compensate for variations in line drop due to variations in load.

Storage Batteries

Correct Methods of Maintenace Will Result in Satisfactory Service and Long Life

THERE ARE two simple ways in which to determine when a storage battery requires charging: (1) When the specific gravity of the electrolyte as indicated by the hydrometer falls to a value of from 1.180 to 1.190. (2) When the voltage on discharge at normal rate falls to 1.8 v. In large commercial installations it is, of course, too laborious a task to test the voltage and specific gravity of each cell individually and a "pilot cell" is therefore chosen from which the required readings are taken.

Batteries should be charged at regular intervals when in use and to keep them in good condition should be given an overcharge about once every two weeks. The normal charging rate for any particular battery is usually specified by the manufacturer and is dependent upon the area of the positive plate surface. Ordinarily it may be taken at 6 amp. per sq. ft. of positive plate surface. Charging rates are usually based on 8 hr. charging time, but these may be exceeded within reasonable limits. If a higher rate is used the hours must be proportionately diminished so that the product of the hours by amperes will remain a constant.

Discharging

The efficiency of a storage battery does not, as might be thought, depend directly upon the rate of discharge. If current be taken out at a high rate and a resulting small capacity be obtained, it does not follow that the efficiency suffers a corresponding decrease. It will be found, as a result of such a high rate of discharge, that the amount of electrical energy required for the succeeding charge will not be as great as would be required had a lower rate of discharge been used. Charging and discharging at high current densities increases the heating and gassing losses, thereby decreasing the efficiency.

On discharge, the voltage should never be permitted to fall below a value of 1.75 v. per cell with current at the normal rate. Too rapid discharge such as might be caused by excessive overload is apt to injure the plates mechanically. If they are of the composite type they may buckle and the active material disintegrate.

Voltage Test

The voltmeter reading of a cell on open circuit indicates nothing about its condition as to charge or

discharge. A voltage test should only be taken when the cell is charging or discharging at its normal rate. Normal voltage should be between 2.00 and 2.05 v.

The internal resistance of a storage cell is numerically equal to the difference between the voltage on charge and that of discharge divided by the current in amperes.

Specific Gravity Test

Hydrometer readings of the electrolyte should be taken at least once a week and the density maintained should not differ from the standard density (which is usually 1.200) by more than 0.005. The exact values of the range in specific gravity between a fully charged cell and a discharged cell vary with different types and sizes of cells; the range is, however, usually specified as 1.180 for a discharged cell to 1.240 for a completely charged cell.

Inspection

Inspection should take place at regular intervals. Each cell should be examined at least once a month. To avoid such inspection taking up too much time, it is customary in the case of large installations to divide the cells into groups and inspect a certain group each day. In this way the time of inspection is spread over a long period.

The use of a portable electric lamp will be found useful in this work and care must be taken to look between all the plates for foreign substance. All terminals should be examined to see that the individual plates make good contact with the connecting straps. If bolt connections are used they should be looked at, as the soft lead of the straps and nuts tends to "flow" under pressure and joints that were tight when installed often loosen up. Insulator supports also require examining as they sometimes crack and cause short circuiting of the cells.

Removing Solution

In preparing new electrolyte, only chemically pure acid and water should be used. Concentrated sulphuric acid usually has a specific gravity of 1.835. This is too strong for use as electrolyte and it must, therefore, be diluted with pure water until a mixture having a specific gravity of about 1.200 is obtained. Caution must be used in doing this. Use a glass, earthenware or lead vessel for mixing purposes. Never use a metallic vessel other than lead. When diluting, the acid must be poured into the water slowly and with extreme caution; never pour the water into the acid because the powerful reaction and consequent boiling may throw the acid into the operator's face. Stir the mixture with a wooden rod and allow it to cool before testing with the hydrometer.

Before putting the electrolyte into the cells all the circuits connecting the battery with the charging source must be charged immediately. The electrolyte should cover the tops of the plates to a depth of ½ in.

Overhauling

Whenever a storage battery begins to show signs of wear by a decided lowering of efficiency it should be dissembled and given a thorough overhauling. In disassembling, remove the entire element from the cell and by slightly spreading the plates withdraw the separators one at a time. The two groups of plates, positive and negative, can then be separated.

Plates, particularly the positives, should be examined for buckling, loss of active material, and sulphation. If the negative plates are found to be in good condition they should not be allowed to dry but should be placed in water or electrolyte. This will effect a saving in time required for charging after reassembling. Wood separators should be inspected for wearing off of the ribs, holes, cracks, etc., and if in good condition may be used again, although on account of their cheapness it is customary to renew them each time a battery is overhauled. It is also well to renew this electrolyte when overhauling but before discarding the old, take a hydrometer reading so as to determine the proper gravity of the new electrolyte to be used. This, of course, is necessary only when the old plates are reused.

When reassembling, care must be taken to place separators between all plates, for to leave one out results in a short-circuited cell. If the old plates and new separators are used, the specific gravity of the new electrolyte should be a trifle higher than that of the discarded electrolyte.

Buckling

Buckling or warping of plates is caused by excessive or unequal expansion and indicates the following: that the discharge has been carried too far, the rate too rapid or that the current distribution over the plate was not uniform. Under the action of unequal expansion of the two sides of the plates strains will be set up, causing the plate to warp. If the buckling exists in only a moderate degree, the plates may sometimes be straightened by placing them between two boards and applying heavy pressure. Hammering is not to be recommended as the jarring tends to detach the active material. Badly buckled plates must be discarded. As a precautionary measure against this type of trouble, keep the discharge rate normal, do not carry the discharge too far, and keep the electrolyte circulating.

Sulphation

Sulphation is a term applied to a common and serious type of storage battery trouble which manifests itself in the formation of a white scale on the plates. This scale, known as sulphate, is almost irreducible and causes shedding of active material, buckling, loss of capacity, increase of internal resistance, and lowering of the efficiency of the cell. Since the formation of ordinary lead sulphate in a cell is a perfectly legitimate process, the formation of the white scale might, more correctly, be termed over-sulphation. Over-sulphation may be caused by excessive discharge rate, over-discharge, or too strong an electrolyte. A battery should never be permitted to stand idle or uncharged after discharge, as the sulphate will form rapidly.

The best treatment for sulphated plates is a matter of opinion. Some recommend charging at very low rates for long periods of time, thus reducing the sulphate others believe that high charging rates give better satisfaction. Lyndon is of the opinion that the charging rate of sulphated plates should be determined by means of a thermometer, i. e., that the charging rate should be

as high as possible with the temperature of the electrolyte not to exceed 105 deg. F.

Peeling

Peeling or shedding of active material, as stated previously, may be caused by buckling or by sulphations but may also be due to improper construction of the plates, in which case little can be done to prevent it. It will take place slowly in every storage battery, however, and may be considered as the normal depreciation. The following precautions, if observed, will aid in reducing trouble from peeling to a minimum. Do not overcharge; do not discharge below 1.8 v. and keep the charging rates at or near normal.

Transformers

Discussing the Important Features in Regard to Operation, Testing and Connecting

THE MODERN transformer, while not a perfect converter of energy, probably approaches perfection in this respect nearer than any form of apparatus in commercial use today. The difference between the amount of energy delivered to a transformer and that taken out as useful current represents the losses. These losses appear as heat and unless they are disposed of in a suitable manner will gradually raise the temperature of the transformer until it becomes dangerously high.

While it is true that the losses, expressed in per cent of the total input, are greater in a small transformer than in a large one, the total amount of radiating surface in small transformers as compared with the losses are also much greater. The heat loss in a large transformer may be 40 times as much as in a small unit, yet the total amount of radiating surface in the former may only be four times as much as in the small one. Small transformers, therefore, do not require any special means of cooling other than that provided by their natural radiating surface. Large transformers, on the other hand, do not have sufficient radiating surface to enable them to keep cool and special means must be provided therefore to remove the surplus heat.

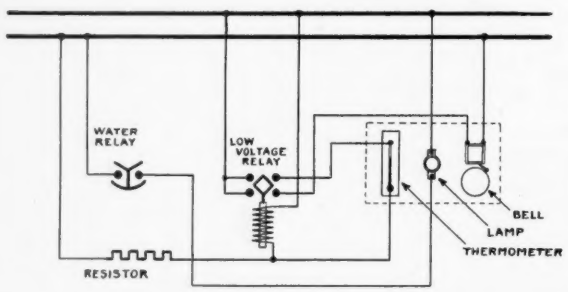


FIG. 1. WATER AND TEMPERATURE ALARM FOR HIGH VOLTAGE POWER TRANSFORMER

The various methods employed for cooling are as follows: self-cooling dry transformers; self-cooling oil-filled transformers; air-cooled transformers cooled by forced air currents; oil-filled transformers cooled by water; transformers cooled by forced current of oil.

Self-cooled dry transformers are made only in small sizes, not over 10 kw. as a rule, and depend for their cooling upon their natural radiation. They require no attention except that the room in which they are installed be kept at a moderate temperature.

In the self-cooling, oil-filled transformer the heat generated in the windings and core is dissipated by the circulation of oil through the transformer structure. Passages or ducts are provided between the coils and in the iron through which the oil circulates, thus bringing about an even distribution of heat throughout the transformer.

The tanks of self-cooling, oil-filled transformers are usually ribbed or corrugated to increase their radiating surface. In large sizes, radiators consisting of nests of tubes are fitted to the outside of the tanks which enables oil circulating through these tubes to radiate much more heat than would be possible if no radiators were provided.

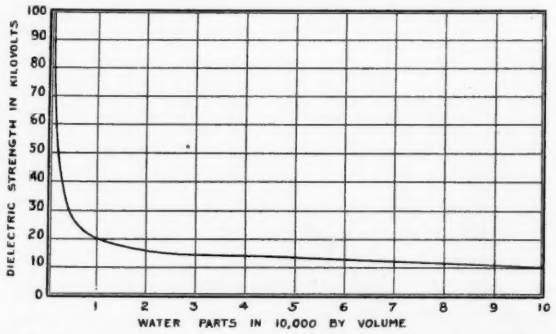


FIG. 2. CURVE SHOWING THE EFFECT OF WATER IN TRANSFORMER OIL

Air-cooled transformers, that is, transformers cooled by a blast of air from a blower, are used to a certain extent in substations and power plants where the use of oil is prohibited by city ordinances due to the fire hazard. When this form of cooling is employed, a number of transformers are usually placed above an air duct supplied by a single blower. The amount of air necessary for cooling depends, of course, upon the efficiency of the transformer. It is usual practice to allow 150 cu. ft. of air per minute for each kilowatt lost. The air velocity should not exceed 500 ft. per min. Under ordinary conditions the difference in temperature between the outgoing air and the incoming air will vary between 12 and 20 deg. C., depending upon the temperature of the surrounding air and the design of the transformer.

Water cooling of oil-filled transformers is one of the most effective methods for dissipating the heat generated and is extensively used in the case of large high voltage units. Great economy of space is secured by this method and as the heat is carried away in the water, such transformers do not raise the temperature of the surrounding air to any material extent. In operation, however, great care must be exercised to avoid interruption in the water supply, and it is usual to

install some form of alarm, Fig. 1, which automatically signals the attendant in case the water supply fails, or if the temperature rises above a certain value.

Insulation

No feature in transformer construction is of greater importance than the selection of proper insulating materials and their correct distribution throughout the windings. The life of the transformer depends almost entirely upon the effectiveness of the insulation and its ability to withstand, continuously, the electrostatic forces which tend to rupture it.

Because of its high dielectric strength and fire-proof qualities, mica is one of the best insulators that can be used for this purpose. It retains its insulating qualities under all normal ranges of temperature and undergoes practically no deterioration whatever. It does not, however, possess the necessary flexibility to adapt it to all forms of construction and is also more expensive than some of the other insulating materials in common use. Varnished or oil-treated cloths, such as Empire cloth, probably come next in value as insulators, not only because of their insulating properties, but also because of their flexibility. Fiber is used extensively, not so much for its insulating properties, but for mechanical separation.

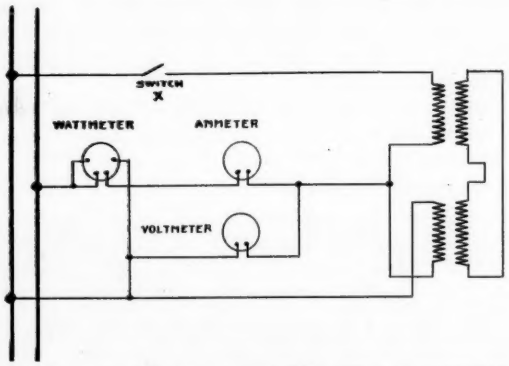


FIG. 3. DIAGRAM OF CONNECTIONS FOR CONDUCTING HEAT RUN

In modern construction the windings of transformers are impregnated with certain insulating compounds, which aid in cementing the turns of wire together and give the coils greater mechanical strength.

For high voltage transformers, mineral oil is one of the most excellent insulators known. Such oils should possess a high flash point and a high fire test in order to reduce the danger of fire or explosion to a minimum. Manufacturers of transformers usually furnish the specifications for the oil to be used in their transformers. While such specifications do not vary greatly with different manufacturers, there are nevertheless slight differences which are probably associated in some way with the constructional features of the transformer. For this reason it is not wise to use oil of any specification but that furnished by the manufacturer of the transformer.

A slight amount of water in transformer oil will destroy its insulating properties to a marked degree. The curve shown in Fig. 2 illustrates this fact very clearly. It shows that the water present in oil must not exceed 0.001 per cent in order to obtain a dielectric strength of 40,000 v.

Tests

While practically all transformers manufactured at the present time are constructed along lines which experience has shown to be successful and are carefully tested and inspected before leaving the factory, yet, because of certain differences between makers as to the value of certain features, the purchaser should be prepared to conduct a series of acceptance tests. The most important tests insofar as the life of the transformer is concerned are the insulation and heat tests. The voltage employed in conducting insulation tests of course depends upon the potential at which the transformer is designed to operate. A test voltage of from 3 to 5 times the working voltage of the winding is usually used. The insulation test must moreover always be made when the transformer is heated to normal full load operating temperature.

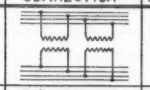
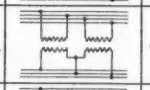
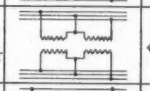
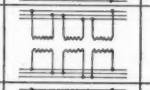
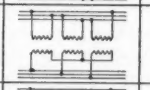
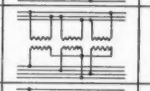
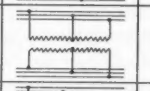
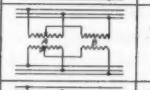
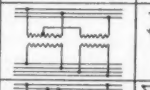
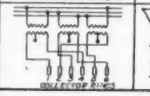
NAME OF SYSTEM	DIAGRAM OF CONNECTION	VOLTAGE RELATION	REMARKS
2 PHASE 4 WIRE TO 2 PHASE 4 WIRE			System consists of 2 separate single phase circuits. The 2 e.m.f.'s and currents being 90 electrical degrees out of phase. Two single phase trans are mostly used.
2 PHASE 4 WIRE TO 2 PHASE 3 WIRE			Voltage across outside wires =1.41 times voltage of each trans. Current in neutral wire is 1.41 times the current in either of the outside wires provided the load is balanced.
2 PHASE 3 WIRE TO 2 PHASE 3 WIRE			Common return on both primary and secondary circuits. Very few systems are operated on this plan.
3 PHASE SYSTEM DELTA-DELTA			E.M.F.'s and currents differ in phase 120 electrical degrees. Delta connected trans. must be wound for full line voltage but for only 58% line current.
3 PHASE DELTA-Y OR VICE VERSA			Used to great extent. Number of turns in trans. winding is only 58% of that required for delta trans. but cross connection of conductors must be correspondingly greater for same output.
3 PHASE DELTA-Y WITH NEUTRAL			Single phase service obtained by tapping between any line and neutral. System results in a raising of 5% in copper assuming 4 wires are of same cross section.
3 PHASE OPEN DELTA OR V CONNECTION			Useful on 3 phase delta connected systems in case one of the phases is damaged. Not possible with core type trans. Reduce current carrying capacity to only 58% of total 3-phase trans. load.
T-T			Requires only 2 single phase trans. A is called main trans. and is provided with 50% voltage tap, to which teaser B is connected. Efficiency somewhat greater than open delta connection.
3 PHASE TO 2 PHASE BALANCED T			Requires 2 trans. which on 3 phase side are connected in T, the number of effective turns in the teaser winding being 86.6% of number turns in main winding.
3 PHASE TO 6 PHASE DIAMETRICAL CONNECTION			Most commonly used of any of the 3 to 6 phase transformations in connection with operation of 6 phase converters.

FIG. 4. VARIOUS TRANSFORMER CONNECTIONS

The duration of the insulation test is usually short. It will depend somewhat upon the severity of the test; the higher the test voltage in comparison with the working potential of the transformer, the shorter should be the application of the test voltage.

The heat test is made by supplying the transformer primary with normal current at normal voltage and loading the secondary until full rated current is obtained. The test should be continued until a constant temperature is reached. In the case of a large trans-

former this test requires considerable current and difficulty is often encountered in dissipating the power supplied by the secondary. If two transformers of the same type are available, the test may be made by connecting them as shown in Fig. 3. With the switch X open, the wattmeter indicates the core losses of both transformers; with X closed, it indicates the total loss. By then subtracting the core loss from the total loss, the copper loss is obtained.

The two tests described above are important in determining whether the transformer will stand up against the effects of high potential and high temperature. In order, however, to determine the characteristics of a transformer, the following tests should be made in addition to the two already enumerated: ratio of transformation; polarity; iron or core loss; resistance and I^2R; regulation; copper loss and impedance; efficiency, and the short circuit test.

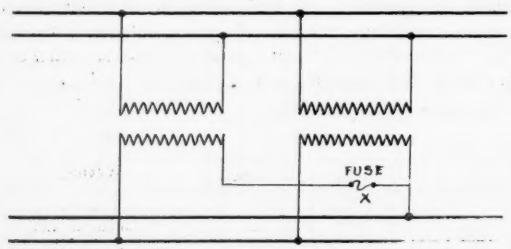


FIG. 5. DIAGRAM OF CONNECTIONS IN TESTING FOR POLARITY

Connections

While it would be impossible to attempt to describe here the great number of transformer connections and manipulations possible in power and general distribution work, a number of the more important connections and their corresponding voltage relations are shown in Fig. 4. These diagrams need no explanation. There are, however, one or two precautions which must be observed in making transformer connections of any kind; these will be briefly discussed.

In order that two or more transformers or groups of transformers may operate successfully in parallel, it is essential that they possess similar characteristics. If, for instance, two transformers possessing the same no-load voltage, but with regulation of three and four per cent respectively, were connected together, the voltage of the two units when operating at full load would differ by a few volts. If the voltage of one of the transformers at full load was 200 v., the other might only be 198 v. This condition, obviously would result in cross currents which would in turn disturb the phase relations and lower the efficiency.

Another requirement in connecting transformers is that the terminals have the same polarity at a given instant. This can be easily determined by connecting the transformers up in the usual manner but with the terminals connected through short strips of fuse wire. If, when the current is thrown on, the fuse blows the connections must be reversed, as it indicates opposite polarity. A simple method of making this test, in the case of two single-phase transformers, is by connecting the two units as shown in Fig. 5. The two terminals at X should be connected by fuse wire, the blowing of which will indicate opposite polarity.

Emergency Provisions

On three-phase circuits where three-phase transformers are used, the burning out of one of the phases would cause considerable inconvenience due to the fact that the entire transformer would have to be disconnected in order to repair the damage. If three single-phase transformers connected in delta are used, however, the burning out of one of the transformers will cause no great amount of trouble. The damaged transformer need merely be cut out and removed for repair while the two remaining transformers are operated open delta or V connected until the third transformer can be replaced. When operating in open delta, however, the transformers can be operated at only 58 per cent of the normal capacity of the three.

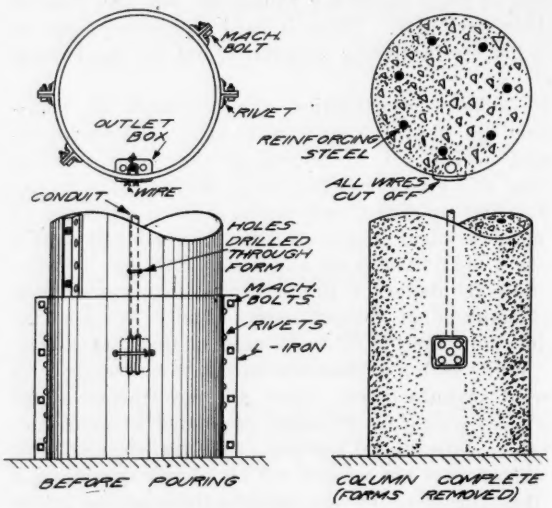
In the case of a burn-out of one phase of a three-phase delta connected transformer, the two remaining phases may be operated by short-circuiting both primary and secondary of the defective phase and cutting it out of the circuit. This cannot be done with Y connected three-phase units, however.

In order to increase the capacity of self-cooling oil-filled transformers fitted with radiators, blowers or fans may be installed in such a way as to force currents of air through the nests of tubes comprising the radiators. In this manner the normal capacity of a transformer has been increased as much as 20 per cent under emergency conditions.

Supporting Conduit Outlet Boxes in Concrete Columns

By T. F. Dickman

A SATISFACTORY method of supporting conduit outlet boxes in the steel forms for concrete columns is suggested in the accompanying sketch. After the steel forms have been erected, but before the reinforcing steel has been placed in them, the outlet



SETTING A CONDUIT OUTLET BOX IN A CONCRETE COLUMN

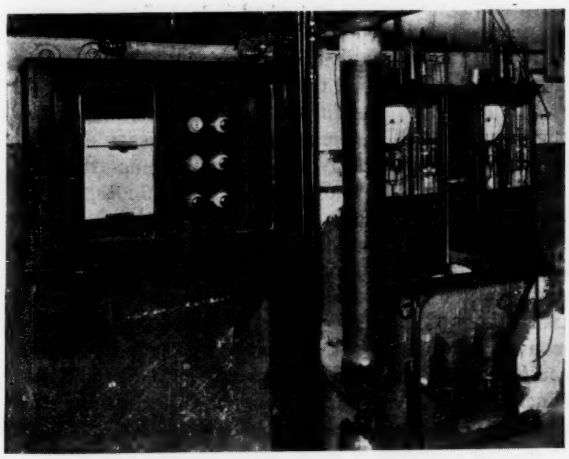
boxes are set in the required locations against the side of the form, the feeding conduit being made up into the box. Then, the box and the conduit are wired to

the form in such a maner that neither can be displaced by the concrete when it is being poured. It is necessary to drill small holes through the sheets of the metal forms with a small-diameter drill to permit of the tie wires being placed. A ½-in. diameter hole is ample. Each outlet box should be stuffed tightly full of paper before it is placed in the form, to prevent the entrance of the concrete while it is being poured. After the forms have been removed, the tie wires which then extend from the concrete column should be snipped off with a pair of nippers or diagonal pliers close to the surface of the column. As a caution—great care should be exercised to insure that the conduits connecting to the boxes are fastened firmly in the form, so that there can be no shifting while the concrete is being poured.

Saving the Fuel Waste

PYROMETERS IN THE POWER PLANT. BY CHARLES B. THWING

LIKE most proverbs, the old saying that "What we don't know, won't hurt us" goes wide of the truth. If there is any part of a modern plant where large preventable losses are the rule rather than the exception, the boiler room is the place. An occasional test made



MULTIPLE RECORD PYROMETER AND COMBINATION DRAFT AND CO_2 RECORDER AT THE PLANT OF JOSEPH CAMPBELL CO., CAMDEN, N. J.

by engineers reveals conditions at the time the test is made, but conditions vary enormously from day to day. To save fuel, the man in charge of firing must have constant indications of draft, CO_2, and temperatures and these values together with the steam flow should be graphically recorded for the study of the plant superintendent. In order of their importance, the temperatures recorded should be: 1, gases entering the stack; 2, gases entering economizer; 3, superheater; 4, feed water.

Pyrometers are available which will record all of these temperatures side by side on the same chart. In addition to those mentioned, it may be worth while to record the temperature at the first or second pass and of the furnace itself, though the last offers more difficulty because of the high temperature involved.

The Campbell's Soup Co., Camden, N. J., has had pyrometers recording its stack temperatures for about 5 yr. Some time ago, it was believed that power soot blowers might be an improvement over the hand lance. A day's run with the power blowers showed a lowering of average stack temperatures of about 170 deg. F. and a consequent fuel saving of approximately 5 per cent. If, in spite of regular cleaning, any boiler shows high or erratic temperatures, the following Sunday sees that boiler thoroughly overhauled for faults in the baffles.

Joseph Bancroft & Sons, Wilmington, Del., keep a line on the performance of their economizers by recording the temperature of feed water as it leaves the economizer. This is accomplished by means of a multiple record electrical resistance thermometer which records all boilers separately on a single recorder located in the superintendent's office. This recorder has been in use for many years and the superintendent would not think of operating without the information which it provides.

Examples of savings like those just mentioned are daily becoming more common. Many firemen are waking up to the need of saving fuel but a fireman's ambition to show good boiler efficiency and substantial fuel saving can be developed to the highest degree only where he is provided with means for finding and maintaining the ideals for which he is striving. Records of boiler pass and flue gas temperatures, superheat, etc., by a pyrometer system may tell such a man whether his firing methods are right, when the fuel or draft are wrong and when soot and scale should be removed. Such records enable a conscientious man to exercise good judgment and prove his worth. To the indifferent fireman they give a warning which he knows cannot be neglected without detection, and which compels him to do better work.

An economizer saves about one per cent of fuel for every 11 deg. of temperature rise imparted to the feed water, so to pay good returns on the investment it must continuously extract a high amount of heat from the gases, which can be done only when soot on the outside and scale on the inside of the tubes are absent. By giving a correct measurement of the temperature drop in the gases, as effected by the economizer, indications from pyrometers in the incoming and outgoing water, give a true index of the conditions within the economizer, and are guides as to how frequently the soot scrapers and scaling turbines should be applied.

Water in Steam Boiler Ashpit

BY JAMES E. NOBLE

A QUESTION which has not been definitely settled is whether water in the ashpit is an improvement or a detriment. My own opinion is that, used intelligently, it is a benefit.

The statement has been made that water in the ashpit will soften the brick in the walls; I doubt this, judging from observations, I know of boilers in use many years, where water is continually used in the ashpits, and no trouble from softened walls has ever shown. When an ashpit is not deep, ashes will collect in a short time, leaving only a small space under the grates, the result being overheated and warped levers, rods, or bars. When water is in the pit, the hot ashes falling into the water will cause a certain amount of vapor, enough to keep the grate bars at such a low temperature that warping will not occur.

Even with a dry ashpit, intelligent firing will do a lot to prevent grate destruction. When a new or clean fire is forced from the start, hot bars and attached clinkers are almost a certainty. With a small amount of ash under the fire, the probability of attached clinkers and overheated bars is lessened; this is the reason some manufacturers of grate bars leave a hollow or groove along the top of each bar, and cross bar in the main bar the idea being that such hollow will fill with fine ash and help preserve the bar from overheat.

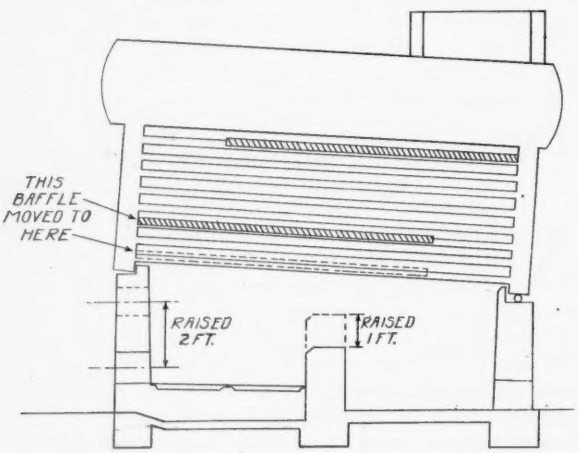
If it is allowable, do not force the fire for about half an hour after cleaning. If it is necessary to force the cleaned fires from the start, then water in the ashpit will help reduce grate repairs. Water in the ashpit will be a benefit when a poor grade of steam coal is used, as such a coal is apt to form so many clinkers that much of the air spaces in the bars will become closed. To obviate any possibility of brick softening with ashpit water, a simple remedy is available. Make a plaster of 2 parts of sand and 1 part portland cement, give the inside of the ashpit, walls and floor, a ½-in. coating with this plaster, 2 hr., or less, will do the job on each boiler, and the ashpit will be made water proof.

When a boiler has a deep ashpit, and ash is not allowed to collect to any great amount, there will be small danger of overheated bars even with a dry pit. I suppose that if a fireman is careless enough to allow ashes to collect to a dangerous amount, he will also be careless enough to neglect running water into the pit, even if he has been instructed to do so.

Burning Veneer Refuse

By R. F. Burke

A SHORT time ago I was called to Florida to examine boiler which, it was claimed, would not carry its rated load. This boiler was a standard longitudinal-drum type with two horizontal baffles. It was equipped with grates for hand firing. The setting, the grates and the baffles were arranged for firing average



CHANGES MADE TO BAFFLE, BRIDGEWALL AND FIREDOOR LOCATION

run of coal. I found that they were burning not coal but veneer refuse and that the boiler was carrying less than 50 per cent of its rating with the fire crowded as much as possible.

Investigation of the fuel, which was refuse from cotton-wood veneer, showed a remarkable moisture content, namely, 60 per cent. I was somewhat doubtful about the ability to use this fuel in a satisfactory manner, but finally decided on some changes as shown in the illustration. In order to be able to carry a heavier fire, I closed the original firing doors and cut other doors about 2 ft. above. The bridgewall I raised about 1 ft. The bottom baffle I moved from the third row to the bottom row. Operated in this way, the fuel burned much faster; in fact, it took two men to fire the boiler and due to the increased furnace capacity and the change in baffles, no difficulty was experienced in carrying 150 per cent of rating. This experience brings out one of the chief advantages of horizontal baffle, namely: the ability to shift them from one place to another with very little trouble to suit the local conditions that cannot be foreseen when originally designed.

Boiler Feed Water Regulators

By W. F. Schaphorst

WHEN considering the installation of boiler feed water regulators, modern practice calls for a regulator that feeds the boiler constantly as long as it is under load, but at the same time varies the water level inversely with the load.

In planning boiler feed water regulator installations, it is well to keep in mind the boiler conditions which may be encountered in the future and regulators should be bought which will accommodate themselves to possible changes. It is frequently necessary to change the pressure being carried, hence a regulator should be selected that has sufficient range to take care of those pressure changes without necessitating reconstruction. It may also become advisable to lower or increase the usual load to be carried on a boiler and a regulator should be chosen that will lend itself to such changes with little or no inconvenience. Briefly this means that the control valve should be so constructed that an ample factor of safety is included for the loads contemplated and at the same time the valve should be so constructed that if a large increase or decrease is to be made in the usual load the inner valve parts can be easily replaced.

Attention should be given to the cost of installation as well as the first cost of the regulator. If it is necessary to change the feed lines to accommodate the regulator, the cost of those changes should be added to the first cost of the regulator.

Consideration should be given to upkeep cost; first the item of repair parts and their cost, and second the cost of the labor usually involved in renewing or replacing any parts or elements. This means selecting a regulator that is strong, rugged, simple and so constructed that the wear is localized and the few parts that are subject to wear can be cheaply and easily renewed. In addition, there should be taken into consideration the cost of operation including steam loss and other expense necessary to keep the regulators in proper operating condition. Avoid, if possible, regulators that must be returned to the factory for repairs or renewals.

Choose a regulator that is designed for the particular conditions under which the boilers are to operate, not only the size of the feed line, but also normal rating.

maximum rating, steam pressure, water pressure, method of firing, method of pump control, etc. If in doubt, ask the regulator manufacturers to furnish flow curves showing the flow that will be obtained by the use of the regulators that are recommended for the plant. Ragged and erratic feeding will almost invariably result when the control valve is too large. Smooth, continuous feeding can be insured by specifying that the regulator control valve shall have a high valve lift—⅝ in. or more.

Many engineers are now specifying that on all pressures above 250 lb., cast steel should be used in place of cast iron on control valves and other water-containing parts of boiler feed water regulators. The writer deems it advisable to adopt this practice as standard and insist upon having cast steel for pressures above 250 lb. Where feed water contains scale, slime, grit, or other foreign impurities, or should wiredrawing occur, insist upon having interior valve parts made of monel metal. In every case, it will be found well worth the added cost.

Preferably, buy from a well established company—a company that stands back of its apparatus, which has specialized in the manufacture of boiler feed water regulators and has sufficient data to enable predetermining exactly what the equipment will do.

Carefully follow the installation directions in every detail as furnished by the manufacturers. Take up unusual conditions with the manufacturers and get detailed information for such installations.

A rugged, well-made regulator will probably outlast the boiler, and installing should be done in a permanent and satisfactory manner. If it is properly installed in the first place, it need not be reinstalled later.

When installing, be sure that when the water level is at the desired point in the boiler the water level in the actuating element of the regulator is at the point which will hold the water level at the desired point under those particular operating load conditions. A simple way to find the proper water level position is by means of an ordinary hose filled with water. The ends of the hose may be carried to any desired point and the water level in those ends observed to locate the height of the regulator operating member.

The regulator should be so constructed that there will be no leakage between the boiler and the element containing the actuating member within the regulator, particularly when boilers are operated at high overloads, because any leakage has a tendency to cause the regulator to carry a false level.

The actuating element of the regulator should be connected to the same drum as the water column, so that the level being maintained by the regulator can be checked by observing the gage glass; but under no conditions should the regulator be connected to or be in any way a part of the water column, as any difficulty with the latter will affect the regulator and this in turn will prevent checking the operation of the regulator by observing the gage glass water level.

Operating instructions furnished by the manufacturer should be closely followed and care should be taken to see that they are understood by the men on every shift. Furthermore, the men on every shift should know definitely what the regulator is supposed to do and should be instructed not to make changes.

After the regulators have been properly installed, make tests to be certain that they are doing what is expected and that the best results are being obtained. One can make simple comparisons between results obtained before and after the installation of the regulator by testing the entire battery (if there are several boilers) rather than individual boilers. If some of the boilers in the battery are controlled by one method of feed, while the remaining boilers are controlled by other methods, a proper comparison cannot be made because of the interference of boilers with one another.

Regulators can be easily checked by artificially raising and lowering the water level or artificially raising and lowering the load and then checking water level variation with steam output. More exhaustive tests can be made by taking simultaneous readings of valve opening, water level, steam output, water input, and where it is obtainable, feed water temperature. Send copies of any tests that are made to the manufacturers and ask them to make comments from the viewpoint of possible improvement in results that might be effected by different manipulation or adjustment.

Inspect all regulators once or twice yearly, paying special attention to any parts that may wear, and send in an order for repair parts in ample time so that they can be installed when the boiler is shut down for cleaning. Regulators should be kept in operation while the boilers are operating. Do not cut them out of service thinking that they will be fixed up and cut back into service "some time later." Tests have been made comparing the efficiency of hand feed with reliable mechanical control and in practically every case it has been found that a properly designed feed water regulator will give better results than are possible by the human water tender.

The engineer should not attempt to make his own repair parts. Certain parts which may appear simple are frequently made with refinements that are important yet almost invisible and may be overlooked by those who are not skilled and experienced in the manufacture of those parts.

For future use it is well to determine the total cost of operating regulators, including cost of installation, and cost of renewals, refilling, or attention of any character. If for any reason a continuous record cannot be kept, it will be well to check the regulator for periods of several months at least, during each year.

THE BUREAU OF MINES has examined samples of lignite taken in the Bluff Point mine, located 16 mi. north of Seldovia, Alaska, and about 140 mi. south of Anchorage in that territory. This lignite is of fair quality and is generally preferred to the bituminous coal brought up from Vancouver Island or the States. It is usually sold locally to the canneries, although occasionally small boats take a load to Cordova and Anchorage. The price at the mine is five dollars per ton of 42 cu. ft. A heating plant, especially designed for the burning of Alaskan lignite, has been installed at the Alaskan Experiment Station at Fairbanks.

TRANSMISSION of handwriting has been accomplished by wireless from Paris, France, to Mt. Desert, Me. The first messages were from M. Briand and Gen. Pershing, the system used being the invention of M. Edouard Belin.

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CONTENTS

Resume of the Boiler Situation. By A. D. Bailey. Illustrated 2
Safe and Efficient Boiler Operation. Illustrated 5
Care and Operation of Boiler Furnaces. Illustrated 15
Maintaining Pump Efficiency. Illustrated 22
Injectors. Illustrated 27
Feed Water Heaters. Illustrated 28
Economizers. Illustrated 30
Superheaters. Illustrated 32
Piping. Illustrated 33
Valves. Illustrated 37
Operation and Maintenance of Steam Turbines. By P. W. Thompson 40
The Steam Turbine. Illustrated 42
Steam Engines. Illustrated 46
Valve Setting on Large Engines. By A. C. Waldron. Illustrated 55
Condensers. Illustrated 57
Care of Heating Systems. Illustrated 61
Coal and Ash Handling. Illustrated 65
Breaking Ammonia Joints for Repairs. By J. J. Cosgrove. Illustrated 67
Overhauling the Ice Plant. Illustrated 69
Maintenance of Diesel Engines. By Harte Cooke. Illustrated 74
Requirements of Lubricating Oil for Diesel Engines 75
The Plant Operator's Job. By A. T. Hunt 76
Generators. Illustrated 78
Motors. Illustrated 85
Electric Circuits. Illustrated 88
Storage Batteries 94
Transformers. Illustrated 96
Supporting Conduit Outlet Boxes in Concrete Columns. By T. F. Dickman. Illustrated 98
Saving the Fuel Waste. By Charles B. Thwing. Illustrated 98
Water in Steam Boiler Ashpit. By James E. Noble 99
Burning Veneer Refuse. By R. F. Burke. Illustrated 100
Boiler Feed Water Regulators. By W. F. Schaphorst 100
Editorial: Limitation of Armaments 102
Off Duty 103
News Notes 104
Books and Catalogs 104

Limitation of Armaments

Reduction of the leading navies of the world seems now assured, as well as an agreement by which the probability of war over differences on far eastern problems will be made remote. This is good, so far as it goes, and has an important bearing on political stability and reduction of expense in the United States, Great Britain and Japan. It promises little relief, however, to the situation in world trade, and has practically no effect on continental Europe where lie the chief difficulties in finance and economics.

European countries need financial aid, credit on raw materials, loans for rehabilitation if industries are to get going; and such aid can come only from the United States. Not from the Government, for the policy is fixed that no further loans will be made by the United States as a government to other governments. The problem of repaying such loans is already so complex as to puzzle and annoy the statesmen of all countries; but aid must be extended by private agencies, banks, export houses and manufacturers. In order that this may be possible, confidence in the industrial future of European industries must be established, and in their ability to pay their debts.

Under present conditions, Europe is loaded with taxes, yet nearly every country shows an income less than expenses, hence a deficit which is being met by the issue of paper money, a process of inflation which depreciates its value and lowers the exchange rate compared to the U. S. dollar. This continually increases the high cost of materials and products bought by Europe from the United States, and results in a loss to the seller if the price is made in foreign money and credit is extended.

Comparison of the total yearly cost of land armament of the European countries and the total deficit of those countries for the year shows that the two are about equal. Hence, if agreement can be reached for reduction of land armament from the present force of between three and four million men with their equipment to the minimum needed for maintaining order within the countries, an important step will have been taken towards doing away with the deficit.

This will reduce the cause for inflation of currency and help to stabilize exchange; but further economic agreements will be needed to ensure that industrial stability is established and confidence restored. Therefore, in any conference called for remedying present conditions in Europe and in world trade, it is essential that besides representatives of the governments, there should be representatives of business, agriculture, finance and labor. Such a conference should be assembled, and the sooner the better.

What have we, as citizens, to do with this? The administration has shown itself in sympathy with making agreements which will reduce the causes of war and assist the industrial recovery of the world; and it will certainly take the initiative toward such a conference if it is sure that the people of the United States desire it. Industrial depression is not peculiar to this country; the whole world is suffering, and our improvement must, to a large extent, go hand in hand with improvement in other countries, for the exportation of products of agriculture, mining and manufacturing is the balance that makes for good or bad business.

The United States must act as the banker for the world, and is the one to take the lead in formulating policies and limitations if credit is to be extended. Agitation for the calling of a conference on economic agreements and the limitation of land armament, which is not likely to reach decision in the present conference, is being pushed by the general committee on limitation of armament, and it is desirable that bodies of engineers inform themselves fully on the situation and take such action as they deem wise to assist in the movement. Volunteer speakers are available and can be secured by writing to the committee at 1319 F street, Washington, D. C. It is to the interest of all American business men and workers that the conference be held in the same spirit of fairness and conciliation that has characterized the proceedings of the present conference, and that steps be taken to get industry back on its feet. It is, therefore, important that we all use our best efforts to bring about such a result.

May 1922 see universal adoption of the principle and practice of settling differences between nations and between men by conference and concession, and the growth of the spirit of co-operation among all men for the welfare of all men.

Off Duty

Necessity is the mother of invention. Here in America, where one may step aboard the Twentieth Century Limited in New York City shortly after lunch, and after a pleasant, comfortable journey, arrive in Chicago the next morning in time for breakfast, it is perhaps only natural that progress in the field of commercial aviation has been retarded. There has been no actual necessity for travel by air. In Europe, on the other hand, where travel by rail is tedious to say the least, where the service is poor and where long stretches of railroad are broken up by international boundaries, travel by air has proved a great convenience by virtue of its being, not a novelty, but an actual necessity. As a consequence, progress in commercial aviation has developed by leaps and bounds.

Take in Paris for instance. Suppose you wish to go to London, Nice, Brussels, Amsterdam, Venice, or any other place of importance. What do you do? Do you hike over to the railroad station, purchase a ticket for any of these points and make up your mind to suffer the inconvenience of a long, tiresome ride in a stuffy compartment of a railway coach? Do you? Not by a long shot—not if you are up to date. Instead, you hotfoot it over to the rooms of the Paris Old Colony Club and there at your leisure consult an air time table for a plane which will bring you to your destination at a time suitable to your convenience. You will have plenty of choice; in fact, you will find that airplanes are leaving Le Bourget aerodrome near Paris at the rate of two every five minutes.

Europe is already a network of commercial air routes. One can now leave Copenhagen at 10:30 a. m. on the Transcontinental Air Limited—replete with buffet service and bar—and arrive at Hamburg at 12:40, Bremen at 2:00 p. m., Amsterdam at 5:15 p. m. and Rotterdam at 6:00. At Rotterdam one can hop into a fast three-hour plane to London or can proceed through Europe via Brussels and Paris. This can be done either by taking a through air limited for the French capital direct from Rotterdam or Amsterdam, leaving the former place at 1:30 p. m. and arriving at Paris at 5 p. m. or by taking a "local" to Brussels and there change for Paris.

By rail, the journey from the French capital to Warsaw takes a minimum of two and generally three days. By air, says the Old Colony Magazine, one may now leave Paris at 6 a. m., reach Strasbourg for breakfast at 8:30; Prague, Czecho-Slovakia at 1 p. m. for lunch and Warsaw for dinner at 6:30 p. m.

Railroad and boat lines are already beginning to feel the competitive influence of the air service which radiates from Paris. One can take a postal express to Bordeaux and from there taxi-planes can be hired for Toulouse, where the great Air Over-seas Limited leaves for Casablanca and Robat, Morocco. This trip takes nine hours and stops are made, if necessary, at Barcelona, Gibraltar and Algiers.

Berlin expresses can be taken from London, Brussels, Rotterdam, Amsterdam and Hamburg, and from Berlin fast air limiteds leave at all hours of the day for Copenhagen, Stockholm, Munich, Warsaw and Christiania.

The Air "Pullmans" to Constantinople are luxuriously furnished and hold 18 passengers. They make the journey from Paris with one stop at Bucharest in 11 hr. and from Bucharest continue the journey by the Balkan Air Passenger Service to Sofia, Athens and Constantinople.

This, however, is just a beginning. Much more is contemplated. In Spain a group of bankers have already subscribed 50,000,000 pesetas for the institution of a passenger air service between Spain and the Argentine Republic. Three commercial Zeppelins are to be constructed, each capable of holding 60 passengers. The trip between Cadiz and Buenos Aires, a distance of about 7000 mi., will be made in approximately 90 hr. The route will probably be by way of the Canary Islands to Pernambuco, Brazil, and thence to Buenos Aires. The longest ocean trip will extend 2000 mi. across the Atlantic from Africa to South America.

This, in brief, is the story of aviation progress in Europe. Kind of takes one's breath away, doesn't it? Makes us feel a bit behind the times. Well, cheer up, who knows but that in a short time the "old man" will sail down to the plant in the morning in his airflivver and after hooking it to one of the smokestacks proceed to bawl "the boys" out for getting too much soot on his wings.

Power Plant Slogans

Keep and Analyze Operating Records in Every Power Plant.
Develop Water Power Sites.
Promote Health and Safety in Power Plants.
Handle Coal and Ashes Mechanically.
Employ Engineers for Engineering Work.

News Notes

THE ATLAS VALVE CO. is now represented in Chicago and Detroit by the Maher Engineering Co., with offices in Detroit in the David Whitney Building and in Chicago at 30 Michigan Blvd.

CHARLES H. BROMLEY is now manager and chief engineer of the Richardson-Phenix Division of S. F. Bowser & Co., Inc., in charge of filtration and lubrication appliance business, with main office at Fort Wayne, Ind.

JOHN B. DOBSON, who has been southeastern manager for Warren Webster & Co. at Atlanta for more than 17 yr., has been transferred to the home office organization at Camden, N. J. Edward W. Klein has been appointed as southeastern district manager.

THE GTD CORPORATION, of Greenfield, Mass., has placed P. T. Irvin, formerly manager of its drill division, in charge of the small tool division. Mr. Irvin has for the past 3 yr. been sales manager of the Lincoln Twist Drill Co. and prior to that was sales manager of Wells Bros. Co. of Greenfield.

THE QUIGLEY FURNACE SPECIALTIES CO., Inc., New York City, announces it will be represented in the Chicago territory by H. M. Thompson, who was formerly identified with the Thomas Moulding Brick Company, who succeeds Bell & Gossett, former agents. Mr. Thompson will make his headquarters at 105 W. Monroe St., Chicago, Ill.

THE EDISON MEDAL "for meritorious service in electrical science or electrical engineering or electrical art" has been awarded, for the year 1921, to Cummings C. Chesney, chief engineer and general manager of the Pittsfield Works of the General Electric Co. This award was made to Mr. Chesney for his work in the development of transmission apparatus, generators, condensers, transformers and converters during his association with the late William Stanley of the Stanley Electric Mfg. Co. of Pittsfield, Mass., which concern was amalgamated some years ago with the General Electric Co.

U. S. CIVIL SERVICE COMMISSION announces examinations, Jan. 11, March 8, and May 17, 1922, for junior physicist to fill vacancies in the Bureau of Standards, Department of Commerce, Washington, D. C., at $1200 to $1500 a year, and in positions requiring similar qualifications, at these or higher or lower salaries. Appointees whose services are satisfactory may be allowed the increase granted by Congress of $20 a month. Applicants must not have reached their fifty-fifth birthday on the date of the examination. This age limit does not apply to persons entitled to preference because of military or naval service. Apply for Form 1312, stating examination title.

U. S. CIVIL SERVICE COMMISSION announces examinations for (1) Junior Engineer and (2) Junior Technologist, on Jan. 11, March 8, and May 17, 1922, to fill vacancies in the Bureau of Standards, Department of Commerce, for duty in Washington, D. C., or elsewhere, at $1200 to $1500 a year, and in positions requiring similar qualifications, at these or higher or lower salaries. Appointees whose services are satisfactory may be allowed the increase granted by Congress of $20 a month. For Junior Engineer, applicants must not have reached their fifty-fifth birthday, this age limit not applying to persons entitled to preference because of military or naval service; for Junior Technologist, they must not have reached their seventieth birthday on the date of examination. Apply for Form 1312, stating the title of the examination desired, to the Civil Service Commission, Washington, D. C.

Books and Catalogs

THAT THE ENGINEERING profession has taken a leading position in the development of research and informational facilities is one of the facts disclosed by a recent survey made by the National Special Libraries Association. As a result of this investigation, over 1300 special libraries were discovered, many of which are largely concerned with engineering, technology, electricity, chemistry and industrial management.

Engineering libraries of various types are maintained by national and local engineering societies, by colleges and universities, by large manufacturing companies, by professional engineering firms, by public utility companies, and by various other agencies. Some of these libraries have been in existence for many years, but many others have only recently been established. The most complete and comprehensive collection is that of the Engineering Societies Library in New York City.

The complete findings of the Special Libraries Association's survey have recently been published in the form of a "Special Libraries Directory," edited by Dorsey W. Hyde, Jr., president of the association. In so far as is known, this directory represents the first attempt at a comprehensive study of the special information sources of the United States.

AN ILLUSTRATED gate valve circular was lately received from the Ohio Brass Co., Mansfield, O.

THE TRIPLEX No. 1 machine tool for milling, drilling and turning is illustrated and described in Catalog No. 1 from Triplex Machine Tool Corporation, 18 E. 41st St., New York.

CIRCULARS from The Turner Brass Works, Sycamore, Ill., deal with recent improvements in Turner blow torches for gasoline and kerosene and the company's improved air pump.

WHITING CORPORATION, Harvey, Ill., is sending out its new crane catalog, No. 158, superseding No. 151, which describes and illustrates the company's standard crane designs and contains several tables of standard clearances.

ALLIS-CHALMERS Manufacturing Co.'s new bulletin No. 1119 on Steam Turbine and Alternator Units, covering high pressure condensing units of 1500 and 1800 r.p.m., for public utilities, municipal railways and lighting, and all industrial activities, has just been received.

ELECTRIC MOTOR DRIVE for Power Pumps is the title of leaflet 1950, which is being distributed by the Westinghouse Electric & Manufacturing Co. This leaflet gives a discussion of the advantages of the use of electricity for this work, and it specifically points out the type of motor which should be used.